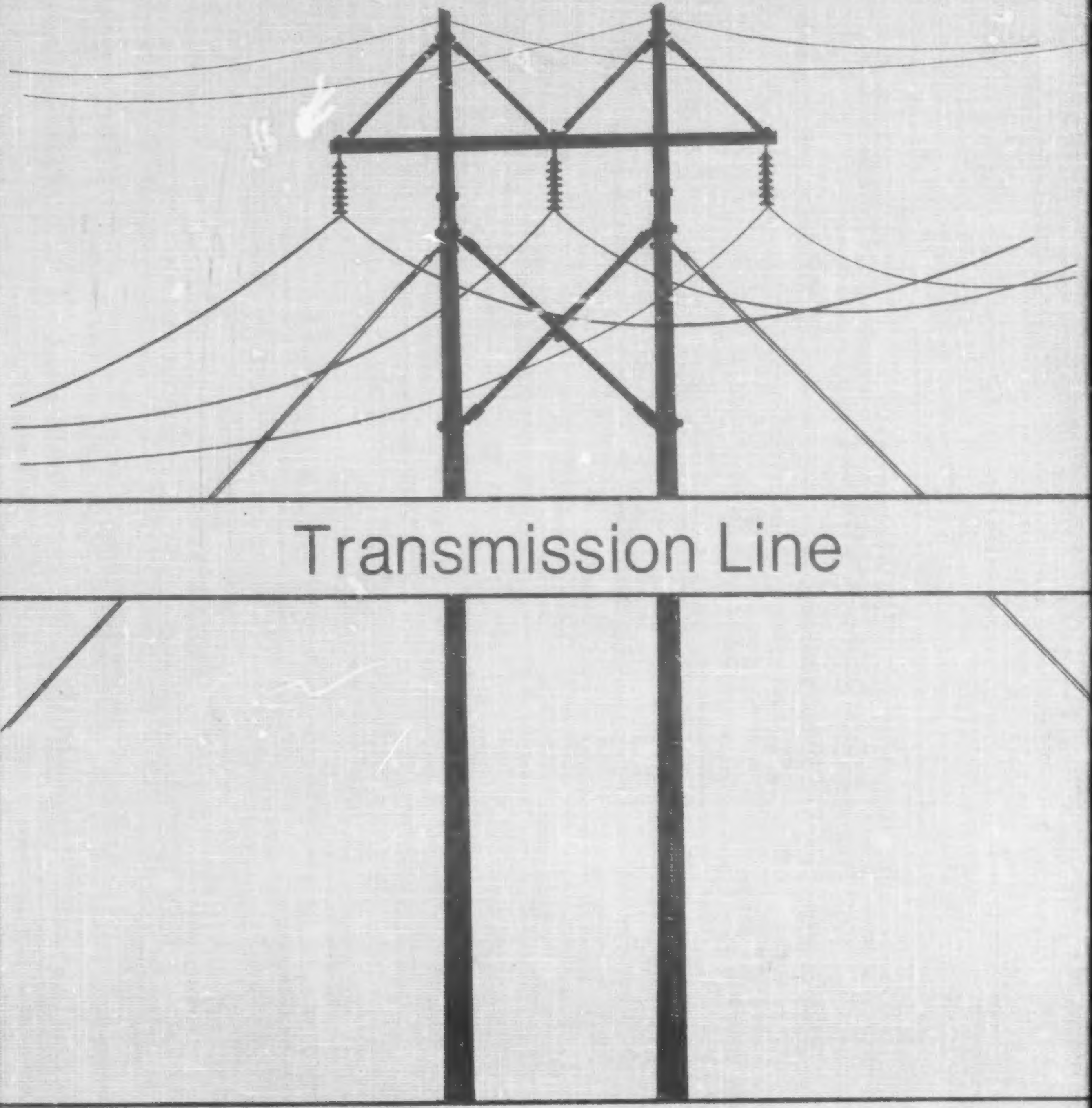
A Water Resources
Technical Publication

UNITED STATES
DEPARTMENT OF THE INTERIOR
Water and Power Resources Service



Transmission Line

Design Manual

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UNITED STATES
DEPARTMENT OF THE INTERIOR
Water and Power Resources Service
Denver, Colorado
1980

Transmission Line Design Manual

by
Holland H. Farr

A guide for the investigation, development,
and design of power transmission lines.

A Water Resources Technical Publication

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources.

This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation.

The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people.

The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions – supplying water and power.

The text of this publication was prepared prior to adoption of the new name; all references to the Bureau of Reclamation or any derivative thereof are to be considered synonymous with the Water and Power Resources Service.

SI METRIC

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PREFACE

The purpose of this manual is to outline the various requirements for, and the procedures to be followed in the design of power transmission lines by the Bureau of Reclamation, U.S. Department of the Interior. Numerous design studies, which have been made on specific aspects of transmission line design, are included with explanations of their applications. Information is presented concerning such aspects as selection of type of construction, conductor sags and tensions, insulation, lightning protection, clearance patterns, galloping conductors, structure limitation and guying charts, and structure spotting. Structure design examples are limited to wood-pole construction. Interpretations of the National Electrical Safety Code and other codes are made as required. Some of the example problems were developed when the sixth edition of NESC was current, and are so noted; however, most examples use the 1977 edition of NESC.

The transmission line network of the Bureau, while considered sparce by some standards, encompasses some 16 000 circuit miles of lines having voltages up to and including 500 kilovolts. In addition, to properly distribute this power, Bureau engineers have also designed and built some 300 substations and switchyards. This total transmission system represents an installed transformer capacity of approximately 22 million kilovolt amperes. In many areas, a Bureau line is the only source of electricity and, if an outage occurs, an area may be completely without power. The vast land area covered by Bureau lines offers almost every conceivable type of climatic condition, and because a large percentage of lines are in remote areas–maintenance is both difficult and time consuming. Therefore, the line designs shown in this manual are more conservative than designs which might ordinarily be considered.

The Bureau of Reclamation recognized the need for this manual and consequently initiated its preparation. With the advent of the Western Area Power Administration, Department of Energy in October of 1977, many of the electrical power features of the Bureau, including most transmission lines, were transferred to the jurisdiction of Energy. However, it was deemed prudent to have the Bureau complete the manual so that the design expertise gained through years of practical experience would be readily available to other organizations as well as being a technical guide for Bureau engineers designing new lines and maintaining the remaining facilities.

This manual contains the engineering tools and concepts that have proven to be successful over many years of transmission line design by the Bureau. The manual is not a textbook, but a useful reference and guide for Bureau designers. In keeping with the Metric Conversion Act of 1975, SI metric units have been shown throughout the manual in addition to U.S. customary units.

There are occasional references to proprietary materials or products in this publication. These must not be construed in any way as an endorsement, as we cannot endorse proprietary products or processes of manufacturers or the services of commercial firms for advertising, publicity, sales, or other purposes.

The author, Mr. Holland H. Farr, has more than 30 years of transmission line design experience as an electrical engineer with the Bureau of Reclamation. He gratefully acknowledges the many contributions to this manual by the personnel of both the Bureau of Reclamation and the Western Area Power Administration. Special recognition is given to F. F. Priest for his encouragement, suggestions, and consultation; to H. J. Kientz for his computer treatment of the concepts; and to R. D. Mohr who provided the technical continuity. This manual was prepared and published by the Bureau of Reclamation, U.S. Department of the Interior, Engineering and Research Center, Denver, Colorado.

ABBREVIATIONS AND SYMBOLS

ACSR	aluminum conductor, steel reinforced
AIEE	American Institute of Electrical Engineers
Alcoa	Aluminum Company of America
ANSI	American National Standards Institute
AWG	American Wire Gage
BIL	basic impulse insulation level
CIGRE	International Conference on Large Electric Systems
EHV	extra high voltage
IEEE	Institute of Electrical and Electronic Engineers
K	conductor loading constant
LP	low point (distance between low points in adjacent spans)
MSI	maximum sag increase
NBS	National Bureau of Standards
NESC	National Electrical Safety Code
OGW	overhead ground wire
SAS	sum of adjacent spans
UHV	ultra high voltage
USBR	U.S. Bureau of Reclamation
GPa	gigapascal
Hz	hertz
kcmil	thousand circular mils
kPa	kilopascal
kV·A	kilovolt ampere
kWh	kilowatt hour
MPa	megapascal
N/m	newtons per meter
N·m	newton meter

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BASIC DATA

1. **Field Data.**–Before design requirements for a transmission line can be formulated, it is necessary to gather certain preliminary information prior to establishing the voltage, type of construction, and the desired conductor and overhead ground wire sizes and types. Usually, the establishment of the voltage on major transmission lines, the number and type of lines required in a given area, and the type of construction to be used depends on a comprehensive system study. This study would include the size and location of generators and loads, and the possibility of using existing transmission facilities. After a system study has established the required voltages and the end points of the transmission lines, the following information is required to establish the details of construction and to prepare designs:

a. Operating voltage of the line.

b. Average and peak loads to be transmitted over the line, or the peak load and estimated load factor.

c. Value in mills per kilowatt hour of the energy to be transmitted, and the value per kilowatt per month or year of capacity to be served.

d. A summary of local climatic conditions including:
  (1) Maximum and minimum temperatures.
  (2) Maximum wind velocities with and without ice.
  (3) Radial thickness of ice expected on the conductors.
  (4) Presence of corrosive smoke or fog atmospheres.

e. A summary of soil conditions, that is, the presence of rock, sand, alkali or other corrosive agents, swamps, and muskeg.

f. A map showing the general route of the line, and locations of terminal and intermediate substations.

g. The length of, and navigation clearance requirements for, river and lake crossings.

The information from a., b., and c., is used to determine the most economic conductor size. The other information is used mainly to establish the required mechanical and structural requirements for the line.

To prepare specifications and designs, the following additional information is required:

h. Whether the line will be constructed by contract or Government forces.

i. Date delivery of power is required.

j. Delivery points for Government-furnished materials, and the proportion of each item of material required at each point.

k. Key map, plan and profile sheets, and special crossing drawings.

l. Drill logs and a summary of footing conditions for steel tower lines or special steel structures.

2. Safety Codes.–The NESC (National Electrical Safety Code), issued by ANSI (American National Standards Institute), contains safety rules for the installation and maintenance of electri supply and communication lines. Because overhead transmission lines are constructed over open area where it is not possible to isolate them from the general public by fencing, it is very important tha certain safety rules be observed in the construction and maintenance of these lines. We construc our transmission lines in accordance with NESC unless the regulations of the state in which th particular transmission line is being constructed are more stringent than those of NESC. The rule do not provide detailed specifications, but rather are intended to cover the more importan requirements from the standpoint of safety to the transmission line work force and to the public The code specifies clearances, grades of construction, design loadings for conductors and supportin structures, strength requirements, and special requirements for crossings of railroads, thoroughfare power circuits, and communication circuits. The code also specifies the general geographic areas i which the design of transmission lines shall be based on light, medium, or heavy loading condition However, when designing a particular transmission line, local weather and climatic conditions shou also be taken into account as local conditions may indicate the use of heavier loading conditions th those prescribed by NESC for that general area.

Loading conditions and conductor and overhead ground wire tensions shall be in accordance wi the latest edition of NESC with exceptions as shown on figure 1 or by specific heavier loadi conditions than those prescribed for the general area in which the line is being designed.

Many states and municipalities have special rules regarding electrical construction; however, mo states recognize NESC as the standard for transmission lines and distribution circuits. Transmissi lines in California should be designed in accordance with *Rules for Overhead Electric Line Constructi General Order No. 95* of the California Public Utilities Commission [1].[1]

Some of the example problems in this manual were developed using the Sixth Edition of NESC [however, most of the problems use the current 1977 Edition [3]. Problems using the old Sixth Editi have been so noted. It is imperative that the latest editions of the applicable state code and NE be used for all designs of transmission lines. Care should be taken to assure that all applicable fact in a code have been used to make certain that at least a minimum allowable design will be met

One of the most important factors of safety, and one that is too often overlooked, is the pro climbing clearance for linemen on structures. Ensure that all structures have the safe climb clearances prescribed by the codes.

3. Cost Estimates.–Two general types of cost estimates are made, a preliminary and a fi engineers' estimate. Preliminary estimates are used to determine the economic feasibility c transmission line, and also to determine the amount of funds to be requested in the budget construction. They are also used to compare the cost of construction on alternate routes, and compare costs of various types of line construction. For example, these comparisons would be u when making system studies in which the economy and feasibility of different voltages and altern types of construction are to be determined. This is especially true at voltages of 230 kV and ab

A final Engineers Cost Estimate, based on the cost of all items involved in the constructio the line, is prepared for each construction specification. Both the preliminary and final estimates based on past cost and bid data and on current prices of materials as quoted by manufacturer

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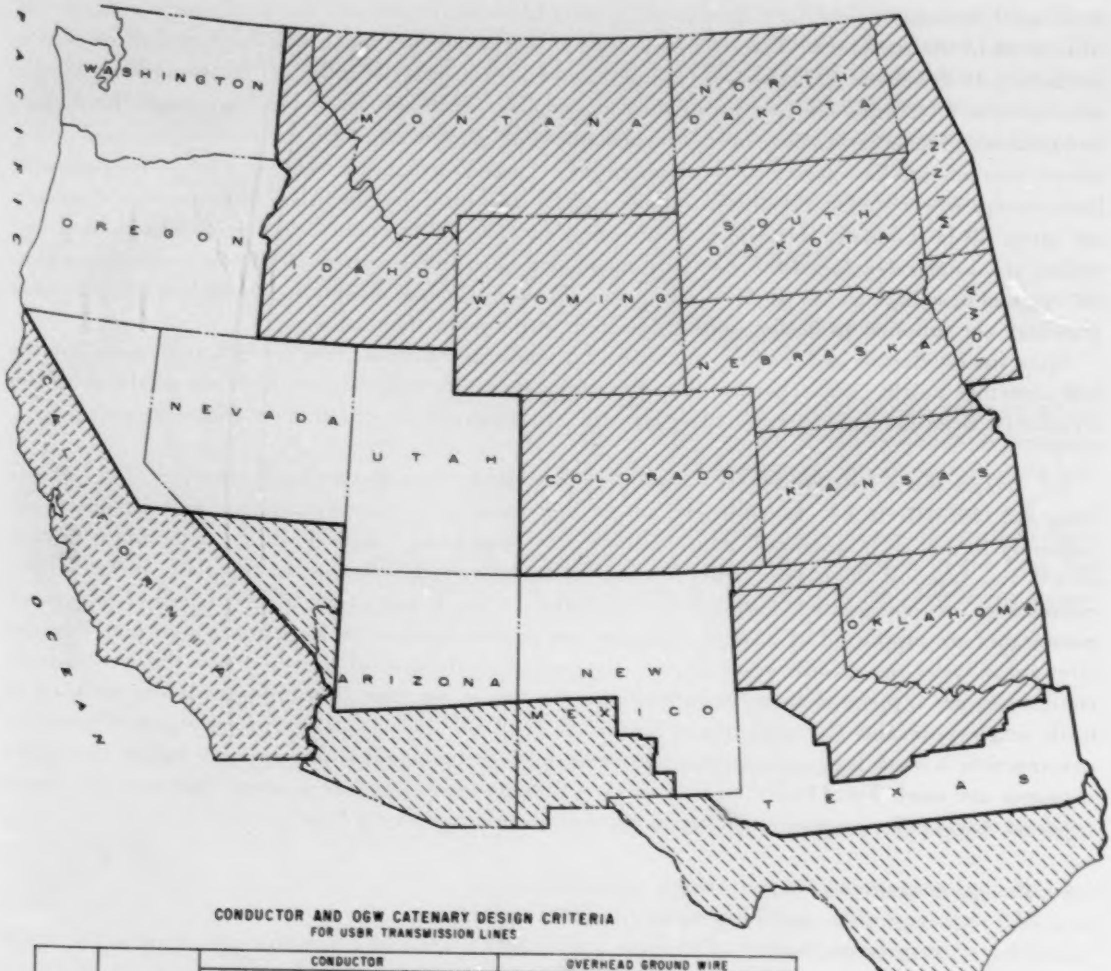
[1] Numbers in brackets refer to items in the Bibliography.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NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINN
IOWA

CONDUCTOR AND OGW CATENARY DESIGN CRITERIA
FOR USBR TRANSMISSION LINES

AREA	LOADING	CONDUCTOR									OVERHEAD GROUND WIRE								
		FULL LOAD INITIAL			NO LOAD INITIAL			NO LOAD FINAL			FULL LOAD INITIAL			NO LOAD INITIAL			NO LOAD FINAL		
		% ULT.	TEMP.		% ULT.	TEMP.		% ULT.	TEMP.		% ULT.	TEMP.		% ULT.	TEMP.		% ULT.	TEMP.	
			°F	°C		°F	°C		°F	°C		°F	°C		°F	°C		°F	°C
▧	Light[1]	50	30	-1.1	33⅓	0	-17.8	25	0	-17.8	50	30	-1.1	33⅓	0	-17.8	[3]25	0	-17.8
□	Medium[1]	50	15	-9.4	33⅓	-20	-28.9	25	-20	-28.9	50	15	-9.4	33⅓	-20	-28.9	[3]25	-20	-28.9
▨	Heavy[1]	50	0	-17.8	33⅓	-40	-40	25	-40	-40	50	0	-17.8	33⅓	-40	-40	[3]25	-40	-40
▩	California Light[2]	50	25	-3.9	33⅓	0	-17.8	25	0	-17.8	50	25	-3.9	33⅓	0	-17.8	[3]25	0	-17.8
	California Heavy[2]	50	0	-17.8	33⅓	-20	-28.9	25	-20	-28.9	50	0	-17.8	33⅓	-20	-28.9	[3]25	-20	-28.9
	All of above							15 Max.	60	15.6							15 Max.	60	15.6

The above criteria apply to conductors and overhead ground wires of any type and material with the exception as noted in footnote 3.

California Heavy Loading applies to all areas above 914-m (3000-ft) elevation, USBR uses NESC Medium Loading in northern California.

[1] National Electrical Safety Code.

[2] General Order No. 95, California Public Utilities Commission.

[3] Extra-high-strength overhead ground wire should be limited to maximum of 20 percent of ultimate strength at temperature indicated.

Figure 1.–Conductor and overhead ground wire catenary design criteria for USBR transmission lines. 104-D-1046. From Dwg. 40-D-5169.

4. Selection of Type of Construction.–When selecting the type of construction to be used on a transmission line, it is necessary to consider the voltage of the line, size and type of conductors to be used, desired or necessary span lengths, costs of construction, and the availability of materials to be used in the structures. The structures used in a transmission line are divided into three classes according to function: (1) tangent, (2) angle, and (3) tension. Usually, 80 to 90 percent of the structures in a transmission line are of the tangent class. Standard wood-pole structures, hardware, and methods of installation have been designed and established as standard design drawings for general use on transmission lines for various voltage ratings. These drawings are to be used for all transmission lines, except where special conditions require special structural designs. All standard design drawings are given 40-D- numbers. Design data drawings, such as sag templates, limitation charts, and sag tables, are usually developed for specific transmission lines and are given 104-D- or project numbers. All original drawings are on file in the Bureau's Denver office, and reproducible prints of applicable drawings are supplied to design units associated with various field offices.

Since the conductor and loading conditions for transmission lines are often different, span lengths and structure heights and types are varied to maintain efficient and economical use of the standard structures. Brief discussions on the basic types of structures are presented in the following paragraphs.

(a) *Single Wood-Pole Structures*.–The Bureau usually uses single wood-pole structures for voltages from 2.3 through 46 kV. In addition, where right-of-way is severely restricted, it is sometimes necessary to use single wood-pole construction for 69- and 115-kV lines. For lines up to and including 69 kV, two types of single-pole structures are used which, with reference to the arrangement of the conductors, are designated *flattop* and *triangular*. In the flattop type of construction, the three conductors are supported by a single crossarm and are arranged in the same horizontal plane. In the triangular type, the middle conductor is supported at the top of the pole and the two outside conductors are supported by a crossarm below the top of the pole. Pin-type insulators are used in both single-pole and H-frame construction. For 69-kV lines, a type of single-pole triangular construction is used; however, suspension insulators with two conductors suspended from the upper crossarm are used. For 115-kV lines, a single wishbone-type structure is used. The common, basic types of single-pole, single-circuit structures and their nomenclature are:

SS = suspension, tangent, single crossarm
SD = suspension, small line angle, double crossarm
SA = suspension, medium line angle (up to 60°), vertical conductor attachment
SAT = tension, large line angle (60° to 90°), vertical conductor attachment
ST = tension, medium line angle (0° to 60°), vertical conductor attachment
STR = suspension, transposition structure

(b) *H-Frame Wood-Pole Structures*.–The Bureau usually uses H-frame, wood-pole structures for voltages from 69 through 161 kV. The H-frame designation originates from the appearance of the tangent structure which has a double-plank crossarm. Occasionally, this type of construction must be used for lower voltages where long spans cannot be avoided; however, it is sometimes used for 230-kV lines. The use of X-braces between the poles is standard on H-frame structures to permit the use of longer spans and heavier conductors, and to support the structures under transverse loading. The use of wood poles longer than 27 m (90 ft) is not recommended, except for very special cases, because they are not economical and are difficult to obtain. For normal wood-pole construction, it is preferred that the majority of poles on lines with overhead ground wires should not exceed 19.8 m

(65 ft) in length; and on lines without overhead ground wires, the majority of poles should not exceed 18.3 m (60 ft).

Although we normally use wood-pole structures for all lines up to 161 kV, occasional situations arise (other than to obtain high clearance for crossings) where it is necessary to use steel towers. For example, it is our policy not to guy any structure within 183 m (600 ft) of a substation; therefore, self-supporting steel structures are used in these locations to permit large line angles, where required, and to permit reduced tensions on conductors and overhead ground wires in the approach spans to the substation.

The basic types of structures for H-frame construction and their nomenclature are:

HS = two-pole, suspension, tangent, double-plank crossarm
3AC = three-pole, suspension, small line angle
3A and 3AB = three-pole, suspension, medium line angle
3TA = three-pole, tension, 0° to 90° line angle

(c) *Single-Circuit Steel Structures*.–Normally, steel construction is used for all voltages above 161 kV. Steel structures are also used for lower voltages under special conditions such as crossings over navigable streams where high clearance and long spans are required, for approach spans into substations and switchyards, and for extra-heavy loadings.

Steel transmission line structures are usually of the self-supporting type and are designed in three general types: (1) tangent, (2) angle, and (3) dead end, according to their function in the line. For many years steel structures were designated by a nomenclature system in which identifying letters were used:

S = Suspension
T = Tension
A = Angle
D = Double Circuit
L = Light
M = Medium
H = Heavy
TR = Transposition

Thus, an SAL-type structure was a single-circuit, suspension, angle structure designed for light climatic loading.

In 1975, the system was changed, and a two-digit number is now used as a basic designation for a set of structures designed for a specific voltage and for specific loadings. The first digit indicates the voltage; for example, a 2 indicates 230 kV. The second digit is a design designator for a particular series of towers. This system permits the steel structure designers to immediately identify the basic set of structures used for any given line. The following letters are added to the two-digit number to designate the function of the structure:

S = Suspension
X = Heavier suspension with small line angle (0° to 5°) capability
ST = Heavier suspension type, no line angle capability, outside phases in suspension, center phase dead-ended
A = Angle (insulators in suspension)
T = Tension with small line angle (0° to 5°) capability
Y = Tension with large line angle (5° to 30°) capability
D = Dead end with variable line angle capability
R = Transposition

Thus, a type 30S structure would be a 345-kV suspension structure with a design designation of zero.

The limitations of a given set of structures will depend upon conductor size, maximum tension in the conductors and overhead ground wires, and the loading area where the structures are to be used.

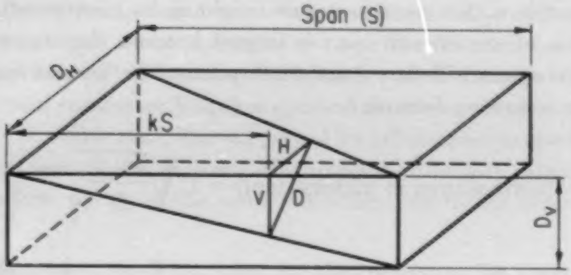
(d) *Double-Circuit Steel Structures*.–Double-circuit steel structures may be used where it is necessary to place two transmission lines on a restricted right-of-way, or if it is desired to reduce the cost of two lines along the same route. On double-circuit structures, the conductors for each circuit are arranged vertically on one side of the structure. In areas where snow and ice loading are not expected, the conductors may be located directly above one another; however, where snow and ice loading are expected, it is desirable to offset the center conductor to minimize the possibility of any contact between the conductors. Contact can be caused by galloping conductors or uneven snow and ice loading on the conductors. For example, if the three conductors are located directly above one another and covered with ice, one of the lower conductors may drop its ice and spring up into the conductor above. Double-circuit steel structures are constructed in the same general types as the single-circuit structures.

(e) *Structures for Special Conditions*.–Special conditions frequently arise in the designing of transmission lines which necessitate the use of special structures. Special structures are required where: (1) a lower voltage line is carried on the same structure below a higher voltage line, (2) a branch line takes off from a main line, (3) switches are required in a line, and (4) long spans, such as those for a river or lake crossing, require higher than normal structures to maintain navigational clearances or wider spacings between conductors. Where navigational clearances over rivers or lakes are required, it is usually necessary to use steel structures to obtain sufficient height.

(f) *Transpositions*.–To maintain balanced conditions of reactance and capacitance on the three phases of a transmission line, at least one transposition barrel should be placed between major terminals. However, it has been determined that for less than 161 km (100 mi) between terminals, the unbalance is not sufficient to affect the operation of the transmission line or the protective relays. The term *barrel*, as used by the Bureau of Reclamation, refers to a section of a three-phase power transmission line of uniform configuration that is divided into three parts of approximately equal length by two transpositions arranged so that each conductor occupies each phase position for one-third the length of the section. Specific instructions regarding transpositions should be given in the design instructions for each transmission line.

The distances between conductors in a transposition must be studied to determine if adequate minimum electrical clearances will be obtained in a given case. If possible, it is helpful to set up a model of the transposition. A model will give good results and will also present the whole problem in perspective. A problem area in a transposition may be difficult to locate correctly without a thorough analysis. A model eliminates the possibility of selecting the wrong area. The model, of course, must be made to scale. A large sheet of plywood for a base, dowels to support the conductors, screws to hold the dowels in the desired locations, and adequate string to represent the conductors provide an inexpensive way of duplicating various questionable line situations such as clearances between conductors, between conductors and structures, or between conductors and guys.

Another method that may be used to determine these clearances is by applying descriptive geometry to the problem. This method should be used after an analysis of the whole system has been made and the problem areas determined. The formulas derived on figure 2 may be applied to many transposition problems.



$$\frac{D_V}{S} = \frac{V}{kS}$$

$$V = kS\,\frac{D_V}{S} = kD_V$$

$$\frac{D_H}{S} = \frac{H}{S-kS}$$

$$H = (S-kS)\,\frac{D_H}{S} = D_H(1-k)$$

$$D = \sqrt{(kD_V)^2 + \left[D_H(1-k)\right]^2}$$

$$D^2 = k^2 D_V{}^2 + (D_H - kD_H)^2$$

$$D^2 = k^2 D_V{}^2 + D_H{}^2 - 2kD_H{}^2 + k^2 D_H{}^2$$

$$D^2 = D_H{}^2 - 2kD_H{}^2 + k^2(D_V{}^2 + D_H{}^2)$$

First derivative of D^2 with respect to k:

$$\frac{dD^2}{dk} = -2D_H{}^2 + 2k(D_V{}^2 + D_H{}^2)$$

Solution of differential equation:

$$D^2 = D_H{}^2 - 2D_H{}^2\,\frac{D_H{}^2}{D_V{}^2 + D_H{}^2} + \frac{(D_H{}^2)^2}{(D_V{}^2 + D_H{}^2)^2}\,(D_V{}^2 + D_H{}^2)$$

$$D^2 = \frac{D_H{}^2\,(D_V{}^2 + D_H{}^2) - 2D_H{}^4 + D_H{}^4}{(D_V{}^2 + D_H{}^2)}$$

$$D^2 = \frac{D_H{}^2\,D_V{}^2 + D_H{}^4 - 2D_H{}^4 + D_H{}^4}{D_V{}^2 + D_H{}^2}$$

$$D = \left(\frac{D_H{}^2 D_V{}^2}{D_V{}^2 + D_H{}^2}\right)^{\frac{1}{2}} = \pm\,\frac{D_H D_V}{(D_V{}^2 + D_H{}^2)^{\frac{1}{2}}}$$

For structures at different elevations:

D_H Remains the same (spacing between conductors on crossarm)

D_V= (Vertical spacing) (± cos θ), where θ is the slope angle.

$$D_V = V\,\frac{\text{Span}}{\sqrt{(\text{Span})^2 + (\text{difference in elevation})^2}}$$

Figure 2.–Mathematical solution for transpositions. 104-D-1047.

(g) *Special Long-Span Construction*.–To take advantage of topographic conditions in areas of rough terrain, it is often necessary to use spans longer than are normal for the voltage under consideration. To obtain the required spacing between conductors for long spans, longer crossarms may be used on single wood-pole structures, and greater pole spacing may be used on H-frame structures. For steel construction, the structures can be designed for any required conductor spacing.

5. **Normal, Ruling, and Effective Spans.**–The *normal span* is used to determine and compare the span lengths obtainable by using different structure heights. The normal span may be defined

as the maximum span attainable with a given structure height and a given conductor clearance above level ground. The usefulness of the normal span is limited because the transmission line profile is seldom level, and the actual spans will vary considerably from the normal span. The normal span can be calculated from the following formula:

$$\text{Normal span in meters (feet)} = C\sqrt{\frac{P-L}{D}}$$

where:

P = height of conductor support for which the normal span is to be calculated, m (ft)
L = conductor clearance above level ground, m (ft)
C = ruling span, m (ft)
D = conductor sag for ruling span C, m (ft)

The *ruling span* may be defined as that span length in which the tension in the conductor, under changes in temperature and loading, will most nearly agree with the average tension in a series of spans of varying lengths between dead ends. A more common definition is that the ruling span is the span length used as a basis for calculating the conductor sags and tensions, constructing the sag template, and preparing the stringing tables. The ruling span for any section of transmission line having n spans of lengths L_1, L_2, $L_3 \ldots L_n$ between dead ends may be calculated from the following equation:

$$\text{Ruling span} = \sqrt{\frac{L_1{}^3 + L_2{}^3 + L_3{}^3 + \ldots L_n{}^3}{L_1 + L_2 + L_3 + \ldots L_n}}$$

To use this equation, the structure locations must be known. However, because the ruling span is used as a basis for calculating the sag template, the ruling span must be estimated before the structures are located. It is always good practice to locate structures for a transmission line so that the span lengths are as uniform as possible. The maximum span length is limited by the strength of the structure and conductor clearance requirements. Therefore, the ruling span can be estimated with sufficient accuracy before the structures are located. One ruling span should usually be selected for the entire line except for certain sections where long and short spans cannot be avoided because of exceptionally rough profile. When this is the case, a longer or shorter ruling span should be used. The conductor must be dead-ended at the point where a change in ruling span occurs because the horizontal tensions in sections of line with different ruling spans do not vary by the same amounts due to variations in temperature and loading. Unbalanced tensions result between sections of different ruling spans. In isolated long spans, such as river crossings or over canyons which are dead-ended at each end, the ruling span is made equal to the actual span.

Effective span is the term used to designate the portion of the conductor which is supported by a structure. If the supports for the conductor at each end of a span are at the same elevation, the low point of the conductor is at the middle of the span and each structure will support one-half of the conductor. In this case, the effective span is equal to the actual span. If one support is higher than the other, the low point of the conductor will be closer to the lower support and each structure will then support that portion of the conductor between the structure and the low point. In effect, considering the conductor load on one side of the structure only, each structure supports one-half the equivalent of a level span equal in length to twice the distance between the structure and the low point of the conductor. This hypothetical span is called the effective span.

To determine the total conductor length supported by any one structure, it is necessary to consider the spans on each side of a structure. The supported length is equal to one-half the sum of the adjacent effective spans; or the sum of the adjacent effective spans for any given structure is equal to twice the distance between low points of the spans on either side of the structure.

6. Selection of Conductors.–When selecting the conductor for a transmission line, it is necessary to consider the voltage of the line, load to be transmitted, value of power losses on the line, corona and radio interference, mechanical strength of the conductor, electrical conductivity, conductor cost, and the availability of the materials used in the conductor.

The voltage for a transmission line is usually selected from system studies and is determined before the line is assigned to the transmission line designers for preparation of designs or design instructions. The minimum diameter of conductor is usually determined by the permissible amount of corona loss; which depends on the voltage, altitude above sea level, and type of conductor surface. Corona loss is negligible for voltages of 46 kV and below.

The mechanical strength of the conductor must be sufficient to carry the wind and ice loads to be imposed upon it without exceeding: (1) 50 percent of the ultimate strength under maximum loading conditions, (2) 25 percent of the ultimate strength under specified no-load conditions after the conductor has assumed its final sag, and (3) 33-1/3 percent of the ultimate strength under initial no-load conditions. When the conductor is loaded by ice and wind, as specified for maximum loading conditions, the conductor is permanently stretched. When the conductor is unloaded, it will assume final sag and tension values, with the sag being greater and the tension being less than they were initially. For example, if we string a 242 mm² (477 kcmil), ACSR, 24/7 conductor on a 213.4-m (700-ft) ruling span, the initial sag at minus 18 °C (0 °F) with no ice and no wind will be 2594 mm (8.5 ft), and the tension will be 19 700 N (4429 lb). The limiting condition, as determined by the Bureau, for this conductor under NESC heavy loading conditions is 33-1/3 percent of the ultimate strength at minus 40 °C (minus 40 °F) initial, no load. The NESC heavy loading conditions are 13-mm (1/2-in) radial ice, 0.19-kPa (4-lb/ft²) transverse wind, and a constant of 4.3782 N/m (0.30 lb/ft). After loading the conductor to a full load tension of 33 362 N (7500 lb), the immediate sag at minus 18 °C (0 °F) with no ice and no wind is 2906 mm (9.53 ft), and the tension is 17 580 N (3954 lb). Ten years after installation, the creep factor in the conductor will cause the sag to increase to 3700 mm (12.14 ft) with a tension of 13 832 N (3110 lb) at minus 18 °C with no ice and no wind.

The strength of the conductor must be high enough and the sag of the conductor small enough to permit the use of reasonably long spans without using excessively high structures. For some small size conductors, the sag is so great that either short spans or very tall structures are required. The use of either short spans or tall structures usually increases the cost of the structures on a line to the point that it becomes more economical to use a larger size conductor that can be supported on shorter structures with longer spans. The maximum permissible sag with standard structures may be limited by galloping conductor considerations in addition to structure height. Section 15 describes the galloping conductor considerations.

The electrical conductivity of the conductor must be high enough to carry the load without heating the conductor to a temperature that would cause annealing and consequent reduction in the strength of the conductor which, in turn, results in greater sag and reduced clearances above the ground. The voltage drop in the line must be limited to about 10 percent; however, this can be controlled by the use of reactors, capacitors, and synchronous condensers to control the vars (reactive volt amperes) transmitted over the line. Usually, the value of power losses in a transmission line is sufficient to justify a larger conductor size than is required to limit heating and voltage drop. A balance must be obtained between the value of losses in the conductor and the fixed charges on the investment in the transmission line such that minimum annual cost will result. Comparison must be made between the various available types of conductors as well as determining the most economical size of any one type of conductor.

Since 1945, ACSR (aluminum conductor, steel reinforced) conductor, because of its lower price, has proved more economical than other conductors, such as copper or Copperweld-copper. Prior to 1945, copper prices were such that copper conductor was more economical than ACSR. Records show that aluminum conductors are now being specified for nearly all new transmission lines, and for about 90 percent of distribution lines.

It is occasionally necessary to consider the availability of the different types of conductors because it may be necessary to complete the transmission line in a short time without regard to the most economical conductor.

Once the route and length of a transmission or distribution line have been determined, and a conductor type and size selected to carry safely and economically the system voltage, current, and power, several mechanical considerations remain which may influence the choice of conductor and will definitely influence the installation methods. The designer must consider such factors as structure heights and locations, span lengths, conductor sags and tensions, and ground clearances. Thus, the designer must have detailed knowledge of conductor sag and tension as a function of span length, temperature, and weight loading. Most of this information is supplied by conductor manufacturers in the form of tables and graphs; however, the designer will usually have to prepare additional aids such as forms, charts, diagrams, and templates, that are related to a specific installation. Figures 3 and 4 show a standard form that USBR designers use for conductor calculations. This form is a variation of a form designed by the Copperweld Steel Co. of Glassport, Pa. [6]. Figure 3 shows metric calculations for the conductor previously mentioned, and figure 4 shows the U.S. customary calculations for the same conductor. A detailed description of this calculation form is given in section 12, chapter II.

7. Stress-Strain Curves.–Most of the mechanical properties required for sag and tension calculations are determined by tensile testing. Wires used in the manufacture of transmission line conductors are tested in full section. The loads determined in a tension test are reported as unit stresses based on an area of the original section:

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

Elongation is measured as the increase in length of a gage-marked length on a test specimen. The elongation is then determined as

$$\frac{(\text{Final Length}) - (\text{Original Length})}{(\text{Original Length})}$$

DCm-578 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR 242 mm² ACSR 24/7
Code Name Flicker
Rated Breaking Strength 76 509 N
Diameter 21 mm
Tension Limitations
Initial -40°C. 33⅓ % 25 502 N
Final -40°C. 25 % 19 127 N
Loaded -18°C. 50 % 38 254 N
Final 15.5°C. 18 % 13 772 N
Computed by ______ Date ______

LOADING Heavy
Linear Force Factor
Dead Load Force (W') 8.9680 N/m
13 mm Ice (W'') 21.1860 N/m
0.19152 kPa Wind 8.9796 N/m
Resultant (W''') 27.3950 N/m
Area (A) 273 mm²
Temp. Coeff. of Linear Exp.
0.000 0 1944 per°C

Permanent Set 0.00 0 504 9
Creep 0.00 0 498
Total 0.00 1 003

Modulus, (E) Final 72.602 GPa
Initial 55.786 GPa
Final AE 19 822 524 N
Initial AE 15 231 252 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.19152 kPa Wind (W''')	-18	0.999 101	0.000 383 7	0.1752	0.021 99	4693	5845	33 362 Initial
Permanent Set & Creep								
No Ice, No Wind (W')	-18	0.999 101	0.000 125 6	0.0971	0.012 16	2594	1911	19 700 Initial
	-1							
	15.5							
	32							
	49							
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.19152 kPa Wind (W''')	-18	0.999 101						
Permanent Set		0.000 505						
No Ice, No Wind (W')	-18	0.999 606	0.000 096 4	0.1088	0.013 62	2906	1911	17 580 PS only
	-1							
	15.5							
	32							
	49							
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.19152 kPa Wind (W''')	-18	0.999 101						
Permanent Set & Creep		0.001 003						
No Ice, No Wind (W')	-18	1.000 104	0.000 096 4	0.1383	0.017 34	3700	1911	13 832 Final
	-1							
	15.5							
	32							
	49							
______ mm Ice			SPAN LENGTH(S) ______ m					
______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							
______ mm Ice			SPAN LENGTH(S) ______ m					
______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							
______ mm Ice			SPAN LENGTH(S) ______ m					
______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							

Figure 3.–Standard sag and tension calculation form (metric).

DC-576 (3-75)

INITIAL
FINAL SAG CALCULATIONS

CONDUCTOR 477 Kcmil ACSR 24/7
Code Name Flicker
Rated Breaking Load 17 200 lb
Diameter 0.846 inch
Tension Limitations:
Initial, -40 °F 33⅓ % 5733 lb
Final, -40 °F 25 % 4300 lb
Loaded, 0 °F 50 % 8600 lb
Final, 60 °F 18 % 3096 lb
Computed by ______ Date ______

LOADING Heavy
Weight Factors:
Dead Weight (W') 0.6145 lb/ft
+1/2 in. Ice (W'') 1.4517 lb/ft
4 lb Wind 0.6153 lb/ft
Resultant: (W''') 1.8767 lb/ft
Area (A) 0.4232 in²
Temp. Coeff. of Linear Exp.:
0.000 0108 per °F

Permanent Set 0.000 504 9
Creep 0.000 498
Total 0.001 003
Modulus, (E) Final 10.53 x 10⁶ lb/in²
Initial 8.091 x 10⁶ lb/in²
Final AE 4 456 296 lb
Initial AE 3 423 688 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
			SPAN LENGTH(S) 700 FEET					
1/2 Inch Ice, 4 lb/ft² Wind(W''')	0	0.999 101	0.000 383 7	0.1752	0.021 99	15.40	1313.69	7500 Initial
Permanent Set & Creep								
No Ice, No Wind (W')	0	0.999 101	0.000 125 6	0.0971	0.012 16	8.51	430.15	4429 Initial
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) 700 FEET					
1/2 Inch Ice, 4 lb/ft² Wind(W''')	0	0.999 101						
Permanent Set		0.000 505						
No Ice, No Wind (W')	0	0.999 606	0.000 096 5	0.1088	0.013 62	9.53	430.15	3954 PS only
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) 700 FEET					
1/2 Inch Ice, 4 lb/ft² Wind(W''')	0	0.999 101						
Permanent Set & Creep		0.001 003						
No Ice, No Wind (W')	0	1.000 104	0.000 096 5	0.1383	0.017 34	12.14	430.15	3110 Final
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) ____ FEET					
____ Inch Ice, ____ lb/ft² Wind(W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) ____ FEET					
____ Inch Ice, ____ lb/ft² Wind(W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) ____ FEET					
____ Inch Ice, ____ lb/ft² Wind(W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120							

Figure 4.–Standard sag and tension calculation form (U.S. customary).

Stress-strain curves are prepared from the data obtained from these tests. As the test specimen is slowly loaded, readings of elongation are made so that the *initial* curve may be plotted. As the specimen is unloaded, elongation readings are again taken so that the *final* curve may be plotted. A typical, stress-strain curve for a wire has a straight line segment, which in the deformation is proportional to the applied load. The unit stress (load divided by original area) is proportional to the unit strain (deformation divided by original gage length). The numerical value of this ratio (stress/strain), usually expressed in gigapascals (pounds per square inch), is the *modulus of elasticity.* For an ACSR conductor, there is no straight line segment on the initial curve, so a straight line average of the portion of the curve under use is used for determination of the modulus of elasticity. The final curve is always a straight line and has the same slope regardless of the maximum load applied, provided the yield strength is not exceeded. The slope of this line is the final modulus of the conductor.

Other characteristics of the test specimen may be determined from the stress-strain test. The *proportional limit* is the stress value at which the deformation ceases to be proportional to the applied load. The maximum stress which can be applied without causing permanent deformation upon release of the load is the *elastic limit.* The *yield strength* is the stress at which the deformation ceases to be proportional to the applied load by a specified percent of elongation (usually 0.2 percent).

Ultimate tensile strength is the maximum tensile stress which a material is capable of sustaining. Tensile strength is calculated from the maximum load during a tension test which is carried to rupture with the original cross-sectional area of the specimen. All metals have lower ultimate strength values when subjected to a fluctuating stress. The amount of decrease will depend upon the range of the fluctuating stress and the number of repetitions. Alcoa (Aluminum Co. of America) states [7] that research and experience in transmission line design indicates that if the limits of variation in tensile stress are approximately 10 percent, the maximum value of the fluctuating stress necessary to produce fracture will be approximately 70 percent of the ultimate strength. This stress is referred to as the *working limit.*

Creep is the plastic deformation that occurs in metal at stresses below its yield strength. Metal that is stressed below the yield point will normally return to its original shape and size when unloaded because of its elasticity. However, if the metal is held under stress for a long period of time, permanent deformation will occur. This deformation is in addition to the expected increase in length resulting from the stress-strain characteristics of the metal.

Figure 5 shows a stress-strain curve that illustrates the origin of values used in conductor sag and tension calculations for transmission lines. An explanation of figure 5 is:

- *ADFG* represents the initial loading curve plotted from test data taken during the loading of a specimen in a stress-strain test.
- The average slope of curve *AF* has been extended and labeled "Average slope of initial from zero to full load." The slope of this line is used for the initial modulus in calculations. The value in this example is 40 GPa (5.8×10^6 lb/in^2).
- *CG* is the final loading curve plotted from test data during the unloading on the test specimen. The slope of this line is the final modulus.
- The conductor represented by the curves is to have a maximum stress of 69 MPa (10 000 lb/in^2) under full load conditions.
- *BF* is drawn parallel to the final curve *CG* and between the points for full load and zero load.
- *AB* is the permanent elongation and is called the *permanent set.*
- The 10-year creep line is drawn from previously computed values. The creep value *DE* is read horizontally between a point on the initial curve and a point on the creep curve at the same stress value.

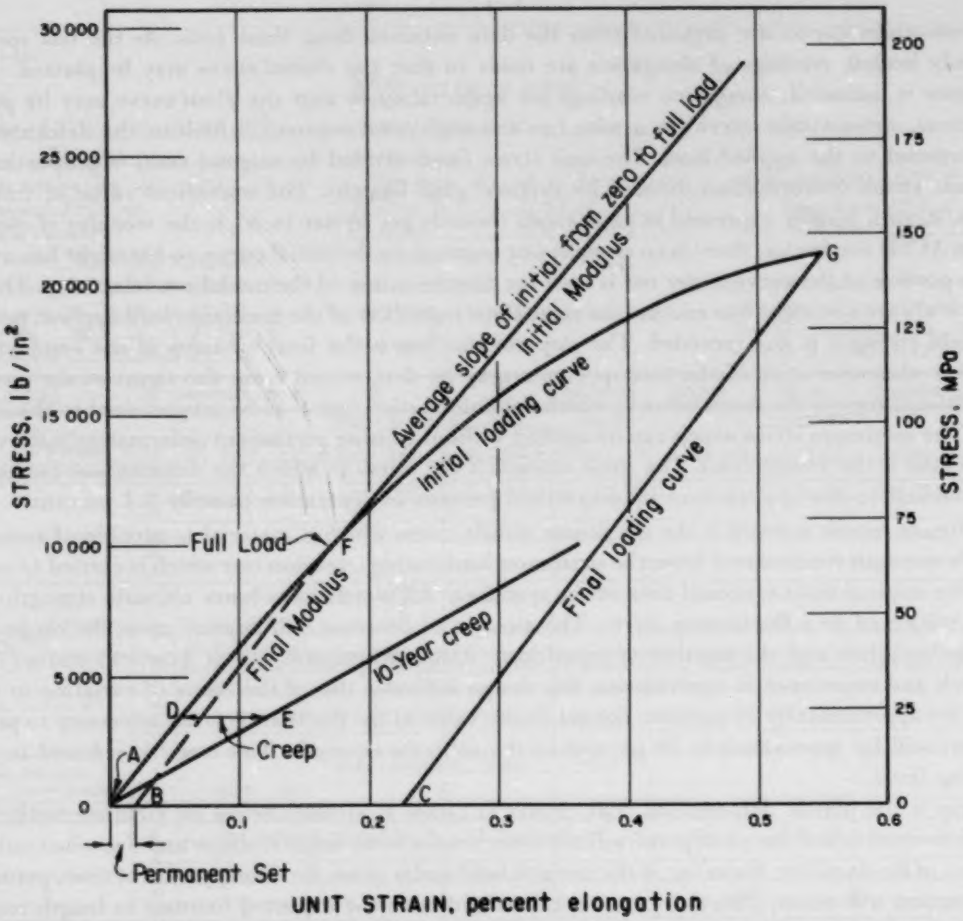


Figure 5.–Stress-strain and creep curves illustrating origin of values used in sag and tension calculations. 104-D-1048.

- **_DE_ represents the creep value over a 10-year period. We assume that the average conductor tension over a period of 10 years will be at 15.5 °C (60 °F) under no load conditions. The USBR limits conductor stress to 18 percent of the ultimate strength at these conditions. The creep values used for our calculations reflect all of these conditions.**

Figure 6 shows stress-strain and creep curves for an ACSR, 26/7 (26 aluminum strands and 7 steel strands) conductor as furnished by the Aluminum Association.

8. The Parabola and the Catenary.–Two curves, the parabola and the catenary, are generally used in the calculations for conductor sags on transmission lines. The parabola, an approximate curve, is often used because it simplifies the calculations. When a wire or cable is assumed to conform to the curve of the parabola, the mass of the wire or cable is assumed to be uniformly distributed along its horizontal projection (the horizontal span length). For the parabolic solution, it is safe to assume that the sag will vary as the square of the span length for spans that are at least double the length of the ruling span.

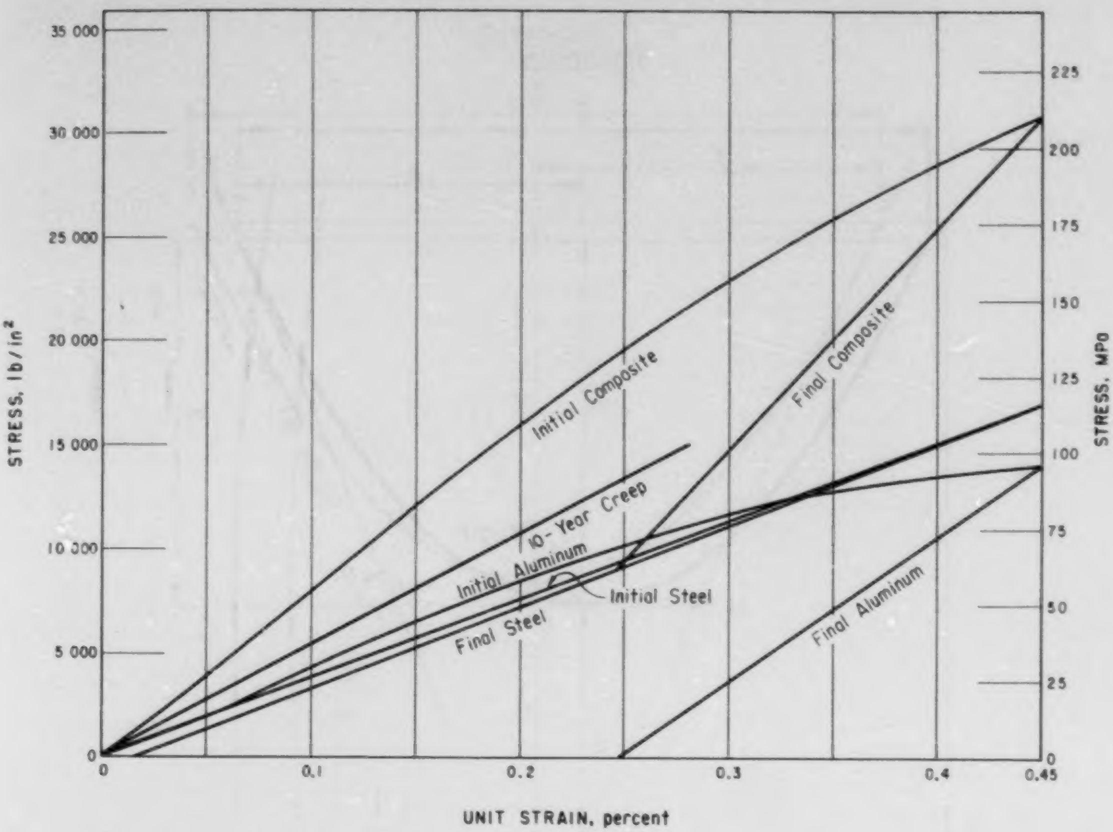
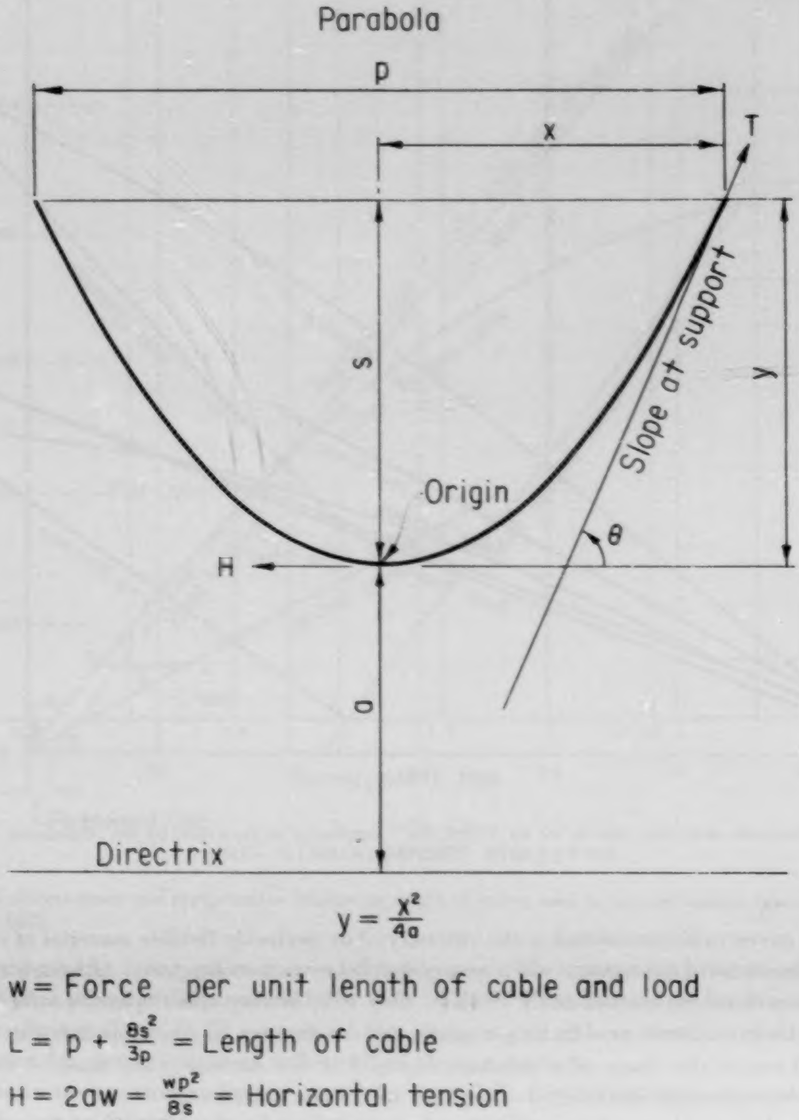


Figure 6.–Stress-strain and creep curves for an ACSR, 26/7 conductor as furnished by the Aluminum Association. 104-D-1049.

The second curve to be considered is the catenary. Any perfectly flexible material of uniform mass will hang in the shape of a catenary when suspended between two supports. Although commercially available wires and cables are not truly flexible, they will, in very short spans, conform closer to a catenary than to any other curve. In longer spans, the conductors may be considered as truly flexible since they will sag in the shape of a catenary curve. For the catenary, the mass of the conductor is assumed to be uniformly distributed along the arc of the conductor.

The sag calculations obtained for a level, reasonably short span with no unusually large sag will be very similar when using either the catenary or the parabola. However, the difference between a catenary and parabolic curve can be appreciable in heavy loading areas with comparatively low tensions in long spans. This difference becomes even more pronounced if the spans are inclined. This is easily understood by realizing that the conductor in an inclined span is actually a small portion of an imaginary long, level span.

Figures 7 and 8 show the parabolic and catenary curves, respectively, and also the commonly used equations for each. Figures 9 and 10 show the metric and U.S. customary sag and tension calculations needed for the following example problems.


Parabola
p
x
T
s
y
Slope at support
Origin
θ
H
a
Directrix

$$y = \frac{x^2}{4a}$$

w = Force per unit length of cable and load

$L = p + \frac{8s^2}{3p}$ = Length of cable

$H = 2aw = \frac{wp^2}{8s}$ = Horizontal tension

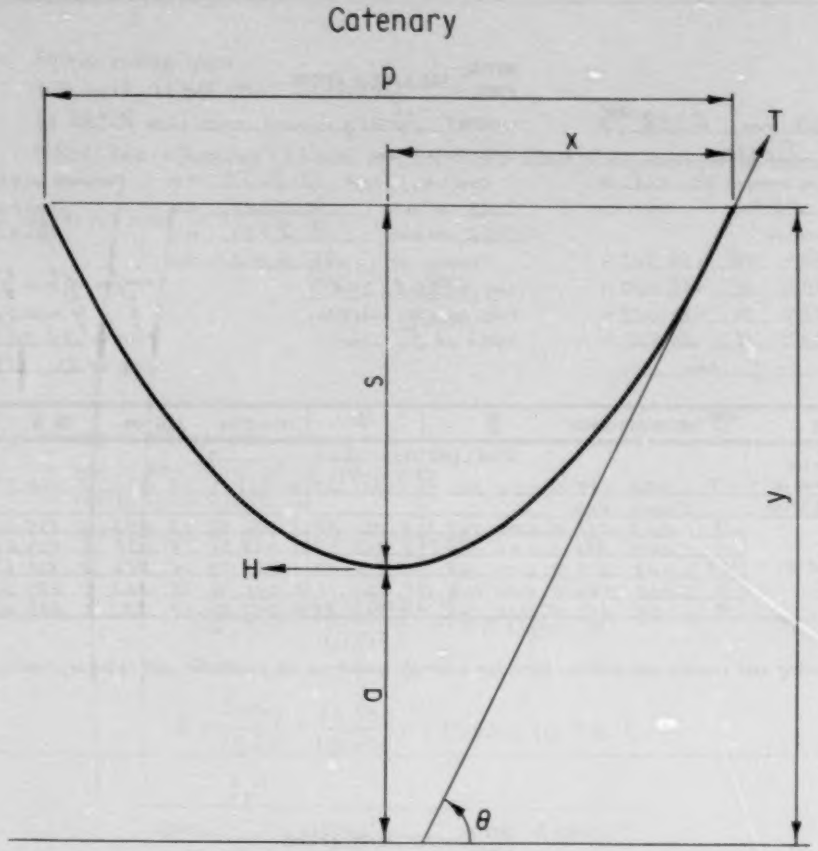
$V = \frac{w(3p^2 + 8s^2)}{6p}$ = Vertical tension

$T = \frac{wp}{8s}\sqrt{p^2 + 16s^2}$ = Maximum tension

$S_1 = \frac{wx^2}{2H}$ = Sag at any point

$S = \frac{wp^2}{8H}$ = Maximum sag

Figure 7.–Parabolic curve and equations. 104-D-1050.



$$y = \frac{a}{2}\left(e^{\frac{x}{a}} + e^{-\frac{x}{a}}\right) = a \cosh \frac{x}{a}$$

w = Force per unit length of cable and load

$L = a\left(e^{\frac{x}{a}} - e^{-\frac{x}{a}}\right) = 2a \sinh \frac{x}{a}$ = Length of cable

$H = aw = T - sw$ = Horizontal tension

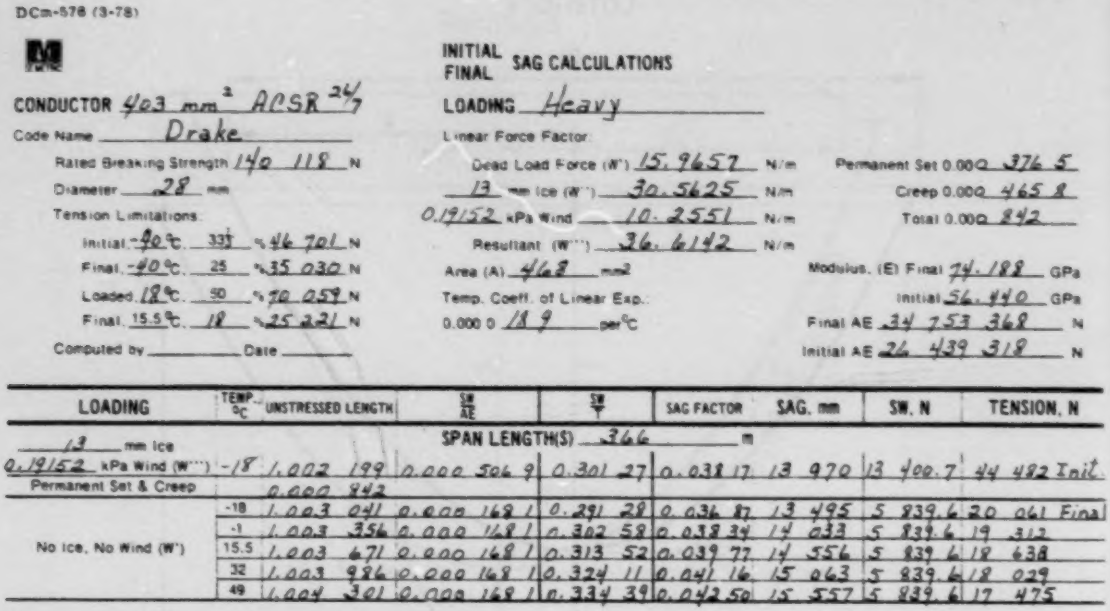
$V = \frac{aw}{2}\left(e^{\frac{x}{a}} - e^{-\frac{x}{a}}\right) = aw \sinh \frac{x}{a}$ = Vertical tension

$T = yw = aw \cosh \frac{x}{a} = H \cosh \frac{x}{a}$ = Maximum tension

$S = y - a = a\left(\cosh \frac{x}{a} - 1\right)$ = Maximum sag

$a = \frac{H}{w}$ = Length of cable whose mass is equal to horizontal tension = Parameter of catenary

Figure 8.–Catenary curve and equations. 104-D-1051.



DCm-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

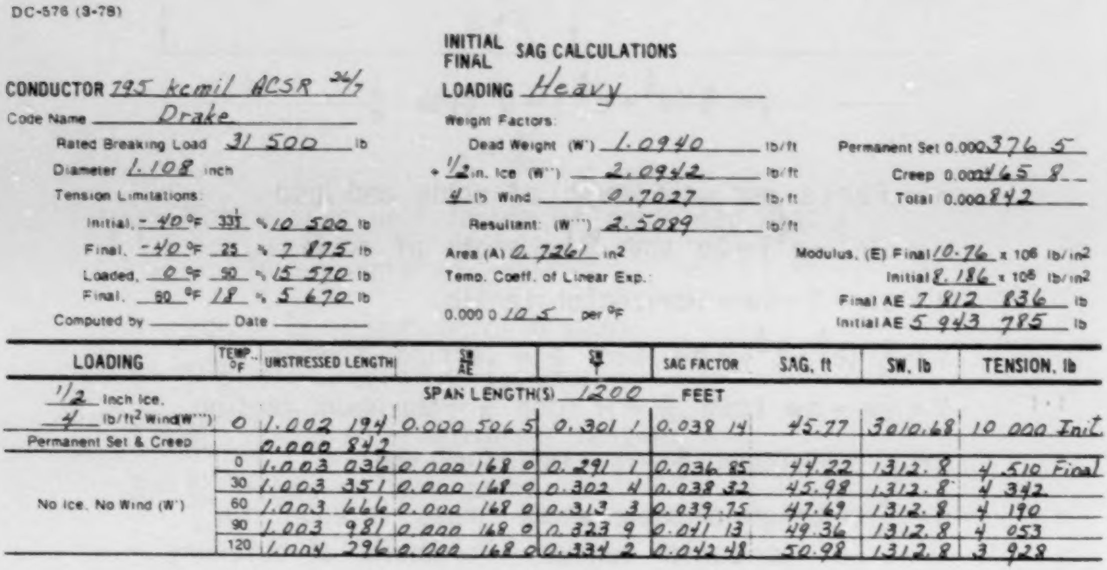
CONDUCTOR 403 mm² ACSR 24/7
Code Name Drake
Rated Breaking Strength 140 118 N
Diameter 28 mm
Tension Limitations:
Initial, -40 °C, 33⅓ % 46 701 N
Final, -40 °C, 25 % 35 030 N
Loaded, 18 °C, 50 % 70 059 N
Final, 15.5 °C, 18 % 25 221 N
Computed by ______ Date ______

LOADING Heavy
Linear Force Factor:
Dead Load Force (W') 15.9657 N/m
13 mm Ice (W'') 30.5625 N/m
0.19152 kPa Wind 10.2551 N/m
Resultant (W''') 36.6142 N/m
Area (A) 468 mm²
Temp. Coeff. of Linear Exp.:
0.000 0 18 9 per °C

Permanent Set 0.000 376 5
Creep 0.000 465 8
Total 0.000 842
Modulus, (E) Final 74.188 GPa
Initial 56.440 GPa
Final AE 34 753 368 N
Initial AE 26 439 318 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	SW/AE	SW/T	SAG FACTOR	SAG, mm	SW, N	TENSION, N
		SPAN LENGTH(S) 366 m						
13 mm Ice 0.19152 kPa Wind (W''')	-18	1.002 199	0.000 506 9	0.301 27	0.038 17	13 970	13 400.7	44 482 Init.
Permanent Set & Creep		0.000 842						
No Ice, No Wind (W')	-18	1.003 041	0.000 168 1	0.291 28	0.036 87	13 495	5 839.6	20 061 Final
	-1	1.003 356	0.000 168 1	0.302 58	0.038 34	14 033	5 839.6	19 312
	15.5	1.003 671	0.000 168 1	0.313 52	0.039 77	14 556	5 839.6	18 638
	32	1.003 986	0.000 168 1	0.324 11	0.041 16	15 063	5 839.6	18 029
	49	1.004 301	0.000 168 1	0.334 39	0.042 50	15 557	5 839.6	17 475

Figure 9.–Sag and tension calculation form for example problems on parabolic and catenary curves (metric).



DC-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

CONDUCTOR 795 kcmil ACSR 26/7
Code Name Drake
Rated Breaking Load 31 500 lb
Diameter 1.108 inch
Tension Limitations:
Initial, -40 °F 33⅓ % 10 500 lb
Final, -40 °F 25 % 7 875 lb
Loaded, 0 °F 50 % 15 570 lb
Final, 60 °F 18 % 5 670 lb
Computed by ______ Date ______

LOADING Heavy
Weight Factors:
Dead Weight (W') 1.0940 lb/ft
+ 1/2 in. Ice (W'') 2.0942 lb/ft
4 lb Wind 0.7027 lb/ft
Resultant: (W''') 2.5089 lb/ft
Area (A) 0.7261 in²
Temp. Coeff. of Linear Exp.:
0.000 0 10 5 per °F

Permanent Set 0.000 376 5
Creep 0.000 465 8
Total 0.000 842
Modulus, (E) Final 10.76 x 10⁶ lb/in²
Initial 8.186 x 10⁶ lb/in²
Final AE 7 812 836 lb
Initial AE 5 943 785 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	SW/AE	SW/T	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
		SPAN LENGTH(S) 1200 FEET						
1/2 Inch Ice, 4 lb/ft² Wind (W''')	0	1.002 194	0.000 506 5	0.301 1	0.038 14	45.77	3010.68	10 000 Init.
Permanent Set & Creep		0.000 842						
No Ice, No Wind (W')	0	1.003 036	0.000 168 0	0.291 1	0.036 85	44.22	1312.8	4 510 Final
	30	1.003 351	0.000 168 0	0.302 4	0.038 32	45.98	1312.8	4 342
	60	1.003 666	0.000 168 0	0.313 3	0.039 75	47.69	1312.8	4 190
	90	1.003 981	0.000 168 0	0.323 9	0.041 13	49.36	1312.8	4 053
	120	1.004 296	0.000 168 0	0.334 2	0.042 48	50.98	1312.8	3 928

Figure 10.–Sag and tension calculation form for example problems on parabolic and catenary curves (U.S. customary).

Example 1.–Parabolic curve (metric)

Assume: 366-m ruling span
403-mm², ACSR, 26/7 conductor
44 482-N maximum tension
NESC heavy loading (13-mm ice, 0.19-kPa wind plus constant at minus 18 °C)

15.5 °C sag at no load = 14 556 mm

$$\frac{Sag_{RS}}{(RS)^2} = \frac{Sag_1}{(Span_1)^2}$$

where:

Sag_{RS} = sag in ruling span, mm
Sag_1 = sag in any other given span, mm
RS = ruling span length, m
$Span_1$ = span length of any other given span, m

$$Sag_1 = \frac{(Sag_{RS})\,(Span_1)^2}{(RS)^2} = K\,(Span_1)^2$$

$$K = \frac{Sag_{RS}}{(RS)^2} = \frac{14.556}{(366)^2} = 1.0866 \times 10^{-4}\,\mathrm{m}^{-1}$$

$Span_1$, m	$(Span_1)^2$, $10^4\,\mathrm{m}^2$	$Sag_1 = K\,(Span_1)^2$, mm
100	1	1 087
200	4	4 346
300	9	9 780
400	16	17 386
500	25	27 166
600	36	39 119
700	49	53 245
800	64	69 544
900	81	88 017
1000	100	108 663

Example 2.–Parabolic curve (U.S. customary)

Assume: 1200-ft ruling span
795 kcmil, ACSR, 26/7 conductor
10 000-lb maximum tension
NESC heavy loading (1/2-in ice, 4-lb/ft² wind plus constant at 0 °F)

60 °F sag at no load = 47.69 ft

$$\frac{Sag_{RS}}{(RS)^2} = \frac{Sag_1}{(Span_1)^2}$$

where:

Sag_{RS} = sag in ruling span, ft
Sag_1 = sag in any other given span, ft
RS = ruling span length, ft
$Span_1$ = span length of any other given span, ft

$$Sag_1 = \frac{(Sag_{RS})\,(Span_1)^2}{(RS)^2} = K\,(Span_1)^2$$

$$K = \frac{Sag_{RS}}{(RS)^2} = \frac{47.69}{(1200)^2} = 3.3118 \times 10^{-5}\ \text{ft}^{-1}$$

$Span_1$, ft	$(Span_1)^2$, $10^5\ \text{ft}^2$	$Sag_1 = K\,(Span_1)^2$, ft
200	0.4	1.32
400	1.6	5.30
600	3.6	11.92
800	6.4	21.20
1000	10.0	33.12
1200	14.4	47.69
1400	19.6	64.91
1600	25.6	84.78
1800	32.4	107.30
2000	40.0	132.47
2200	48.4	160.29
2400	57.6	190.76
2600	67.6	223.88
2800	78.4	259.65
3000	90.0	298.06

Example 3.–Catenary curve (metric)

Assume: 366-m ruling span
403-mm², ACSR, 26/7 conductor
44 482-N maximum tension
NESC heavy loading (13-mm ice, 0.19-kPa wind at minus 18 °C)

15.5 °C sag at no load = 14 556 mm
15.5 °C tension at no load = 18 638 N
From figure 8:
$H = aw = T - sw = 18\,638 - (14.556)\ (15.9657) = 18\,405$ N
$a = H/w = 18\,405/15.9657 = 1152.7839$ m

$x = p/2 = 1/2$ span, m	$\frac{x}{a}$	$\cosh\frac{x}{a} - 1$	Sag $= a\left(\cosh\frac{x}{a} - 1\right)$, mm
50	0.043 373	0.000 940 756	1 084
100	0.086 746	0.003 764 794	4 340
150	0.130 120	0.008 477 558	9 773
200	0.173 493	0.015 087 698	17 393
250	0.216 866	0.023 607 738	27 215
300	0.260 240	0.034 053 971	39 257
350	0.303 613	0.046 445 571	53 542
400	0.346 986	0.060 806 071	70 096
450	0.390 359	0.077 162 490	88 952
500	0.433 733	0.095 546 051	110 144

Example 4.–Catenary curve (U.S. customary)

Assume: 1200-ft ruling span
795 kcmil, ACSR, 26/7 conductor
10 000-lb maximum tension
NESC heavy loading (1/2-in ice, 4-lb/ft² wind at 0 °F)

60 °F sag at no load = 47.69 ft
60 °F tension at no load = 4190 lb
$H = aw = T - sw = 4190 - (47.69)\ (1.0940) = 4137.83$ lb
$a = H/w = 4137.83/1.0940 = 3782.29$ ft

$x = p/2 = 1/2$ span, ft	$\frac{x}{a}$	$\cosh\frac{x}{a} - 1$	Sag $= a\left(\cosh\frac{x}{a} - 1\right)$, ft
100	0.026 439	0.000 349 531	1.322
200	0.052 878	0.001 398 367	5.289
300	0.079 317	0.003 147 243	11.904
400	0.105 756	0.005 597 738	21.172
500	0.132 195	0.008 750 491	33.097
600	0.158 634	0.012 608 781	47.690
700	0.185 073	0.017 174 947	64.961
800	0.211 512	0.022 452 180	84.921
900	0.237 951	0.028 444 171	107.584
1000	0.264 390	0.035 155 107	132.967
1100	0.290 829	0.042 589 680	161.087
1200	0.317 268	0.050 753 087	191.963
1300	0.343 707	0.059 651 036	225.618
1400	0.370 146	0.069 289 745	262.074
1500	0.396 585	0.079 675 954	301.358

Figure 11 is a catenary curve showing the percentage relationship between sag and span length. This relationship may be particularly useful in determining a clearance at any point in a span.

Parabolic and catenary curves are discussed further in chapter II.

9. **Design Instructions.**–A proportion of the design work on transmission lines is delegated to the Regional Directors of the Bureau's seven regions. Design instructions are issued to these directors by the Denver office to cover the technical design of each transmission line and include the following:

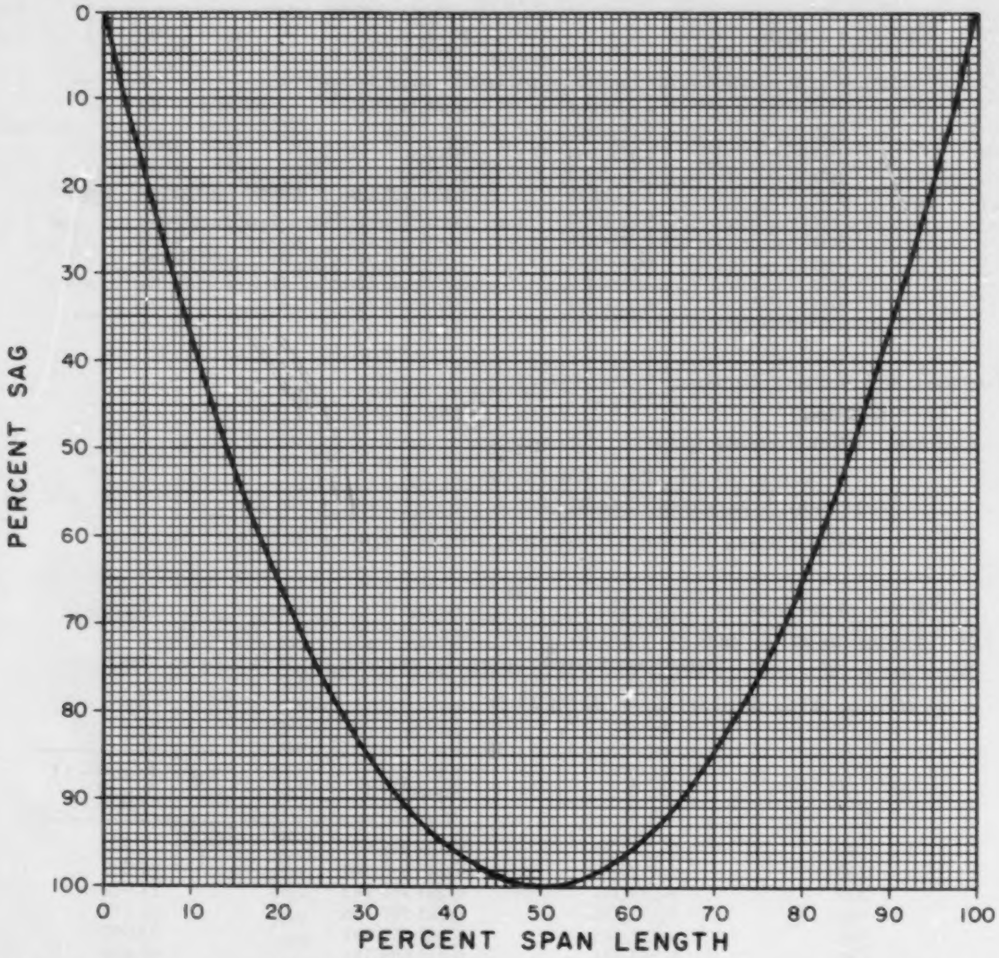


Figure 11.–Catenary curve showing percentage relationship between sag and span length. 104-D-1052.

a. Design data.
  (1) Length of line
  (2) Voltage of line
  (3) Number of circuits
  (4) Type of structures
  (5) Ruling span
  (6) Insulators: number, size, and type
  (7) Conductors and overhead ground wires: number, size, and type
  (8) Maximum tension under loaded conditions for conductors and overhead ground wires
  (9) Final tension at 15.5 °C (60 °F) with no wind for conductors and overhead ground wires
  (10) For steel towers, the horizontal and vertical spacing between conductors and overhead ground wires

(11) For steel towers, the conductor clearances to tower steel

(12) Final sag at 15.5 °C (60 °F) and 49 °C (120 °F) with no load for conductors and overhead ground wires

(13) Midspan clearance at 15.5 °C (60 °F) between the conductors and overhead ground wires

(14) The annual isoceraunic level and the probable number of power outages due to lighting. This number is calculated either per 100 kilometers or per 100 miles of transmission line length; the numerical coefficent for the "per-100-miles" value is 1.6 times the "per-100-kilometers" value.

b. Design loading conditions.

c. Minimum clearances, other than those given in a.

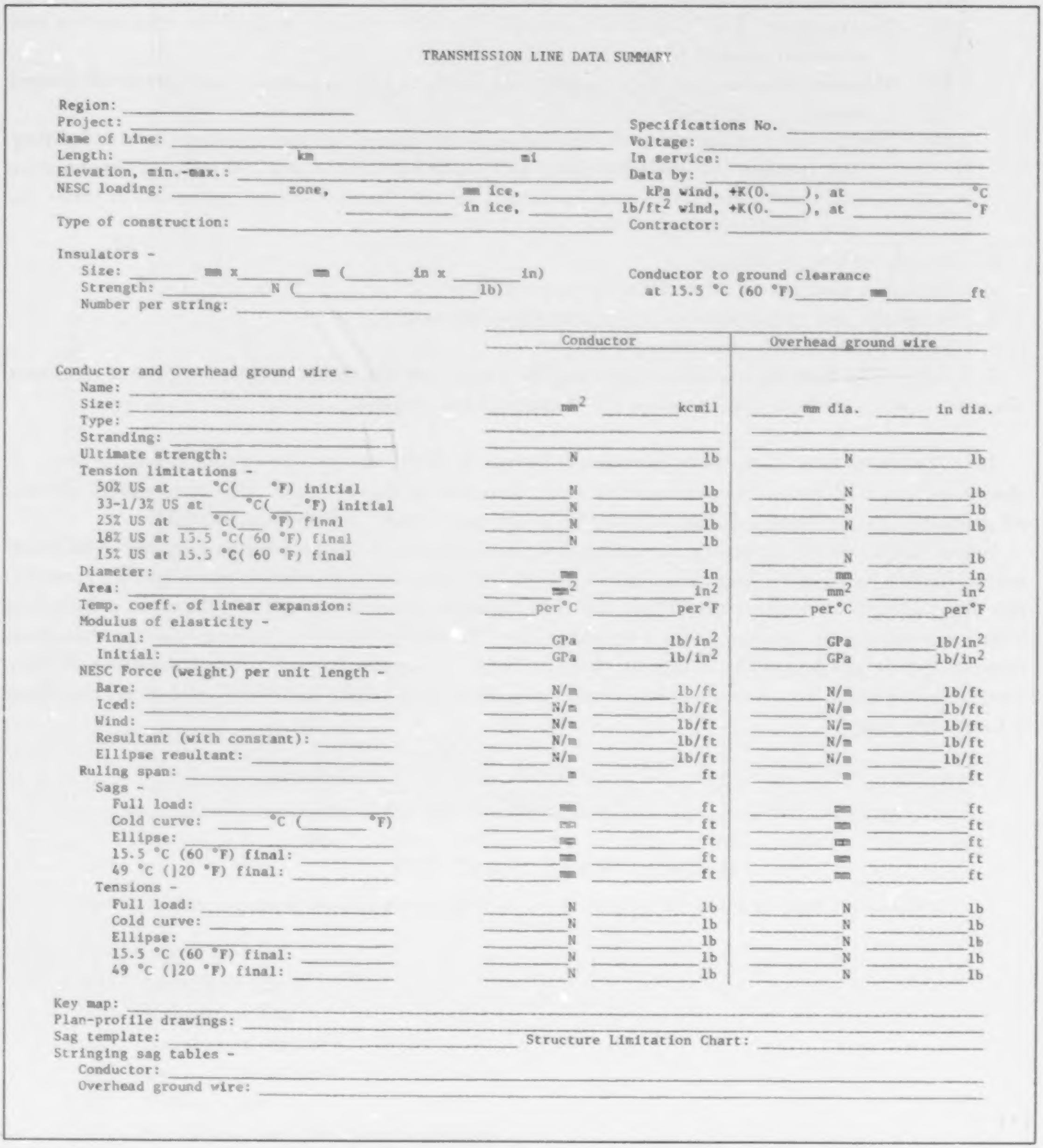
d. Drawings and characteristics of structures to be used.

e. Number and locations of transpositions.

f. Design data drawings including sag templates, structure limitation charts, steel tower clearance diagrams, and conductor height tables for wood-pole structures.

10. Transmission Line Data Summary Form.–A *Transmission Line Data Summary* form, as shown on figure 12, should be prepared for each transmission line designed. This form should contain all pertinent data concerning the line so that a compact, ready reference is available.

Initial entries on the summary form should be made when the design work is assigned. Additional entries should be made as data are obtained, and by the time the transmission line is put into service, the form should be completely filled out. The completed form should be placed in a looseleaf notebook, along with summary sheets for other lines, for easy reference. Nothing is better than good records–if they are kept. The summary sheet is simple in layout, easy to fill out, contains all data normally required, has room for any additional data that might be useful, and is an excellent information source.



TRANSMISSION LINE DATA SUMMARY

Region: ____
Project: ____ Specifications No. ____
Name of Line: ____ Voltage: ____
Length: ____ km ____ mi In service: ____
Elevation, min.-max.: ____ Data by: ____
NESC loading: ____ zone, ____ mm ice, ____ kPa wind, +K(0.____), at ____ °C
____ in ice, ____ lb/ft² wind, +K(0.____), at ____ °F
Type of construction: ____ Contractor: ____

Insulators -
Size: ____ mm x ____ mm (____ in x ____ in)
Strength: ____ N (____ lb)
Number per string: ____

Conductor to ground clearance
at 15.5 °C (60 °F) ____ mm ____ ft

	Conductor		Overhead ground wire	
Conductor and overhead ground wire -				
Name: ____				
Size: ____	____ mm²	____ kcmil	____ mm dia.	____ in dia.
Type: ____				
Stranding: ____	____		____	
Ultimate strength: ____	____ N	____ lb	____ N	____ lb
Tension limitations -				
50% US at ____ °C(____ °F) initial	____ N	____ lb	____ N	____ lb
33-1/3% US at ____ °C(____ °F) initial	____ N	____ lb	____ N	____ lb
25% US at ____ °C(____ °F) final	____ N	____ lb	____ N	____ lb
18% US at 15.5 °C(60 °F) final	____ N	____ lb		
15% US at 15.5 °C(60 °F) final			____ N	____ lb
Diameter: ____	____ mm	____ in	____ mm	____ in
Area: ____	____ mm²	____ in²	____ mm²	____ in²
Temp. coeff. of linear expansion: ____	____ per°C	____ per°F	____ per°C	____ per°F
Modulus of elasticity -				
Final: ____	____ GPa	____ lb/in²	____ GPa	____ lb/in²
Initial: ____	____ GPa	____ lb/in²	____ GPa	____ lb/in²
NESC Force (weight) per unit length -				
Bare: ____	____ N/m	____ lb/ft	____ N/m	____ lb/ft
Iced: ____	____ N/m	____ lb/ft	____ N/m	____ lb/ft
Wind: ____	____ N/m	____ lb/ft	____ N/m	____ lb/ft
Resultant (with constant): ____	____ N/m	____ lb/ft	____ N/m	____ lb/ft
Ellipse resultant: ____	____ N/m	____ lb/ft	____ N/m	____ lb/ft
Ruling span: ____	____ m	____ ft	____ m	____ ft
Sags -				
Full load: ____	____ mm	____ ft	____ mm	____ ft
Cold curve: ____ °C (____ °F)	____ mm	____ ft	____ mm	____ ft
Ellipse: ____	____ mm	____ ft	____ mm	____ ft
15.5 °C (60 °F) final: ____	____ mm	____ ft	____ mm	____ ft
49 °C (120 °F) final: ____	____ mm	____ ft	____ mm	____ ft
Tensions -				
Full load: ____	____ N	____ lb	____ N	____ lb
Cold curve: ____ ____	____ N	____ lb	____ N	____ lb
Ellipse: ____	____ N	____ lb	____ N	____ lb
15.5 °C (60 °F) final: ____	____ N	____ lb	____ N	____ lb
49 °C (120 °F) final: ____	____ N	____ lb	____ N	____ lb

Key map: ____
Plan-profile drawings: ____
Sag template: ____ Structure Limitation Chart: ____
Stringing sag tables -
Conductor: ____
Overhead ground wire: ____

Figure 12.–Transmission line data summary form. 104-D-1053.

CONDUCTOR SAGS AND TENSIONS

11. General Information.–The determination of sags and corresponding tensions for any conductor under various conditions of temperature and loading is of basic importance in transmission line design. This determination enables design elements, such as the most economical span length, to be established and permits the use of sag templates, stringing tables, and other aids. Two general criteria are in use as a basis for making sag and tension calculations: (1) the catenary curve, and (2) the parabolic curve.

If a uniform, perfectly flexible and inelastic length of material, such as a chain or cable, hangs in still air between two fixed supports, it will take the form of a catenary. For the catenary, the mass of the conductor is assumed to be uniformly distributed along the arc of the conductor. The minimum tension in the cable will be at the lowest point of the arc, and the maximum tension will be at the points of support. The tension at any point in the cable will consist of two components: (1) a horizontal component which is uniform throughout the length of the cable, and (2) a vertical component which varies along the curve. This means that the total tension in the cable will also vary along its length. The vertical component of the tension at the low point of the cable is zero.

If it is assumed that the mass of the cable is uniformly distributed along a horizontal line between the points of support, instead of along the cable itself, the resultant mathematical equation for the curve of the cable is that of the parabola. The results of the two methods of calculation (catenary and parabola) are almost identical when the sag is small; however, the difference in results becomes increasingly greater as the sag increases. Since longer spans have larger sags, the difference increases as the span length increases.

Within a limited range of values of the ratio of sag to span, either the catenary or the parabolic method may be used for calculations. Generally, the use of the parabolic method should be limited to spans where the value of this ratio is less than 0.05. The catenary method can also be used for ratios less than 0.05, and should be the method used for ratios between 0.05 and 0.20. For ratios greater than 0.20, the catenary may present difficulty. Fortunately, most transmission lines encountered in practice will involve a sag-to-span ratio of less than 0.20. The error inherent or introduced in sag and tension computations should not be greater than the tolerance allowed in stringing the conductor. In general, the error allowed in stringing is 12 mm (0.04 ft) per 30.5 m (100 ft) of span length for spans up to and including 366 m (1200 ft), and 152 mm (0.5 ft) maximum error for spans greater than 366 m. The curve assumed by the cable in a steep inclined span is actually a portion of a curve for a very large level span, so calculations for steep inclined spans, even though the spans may be short, should be made using the catenary method. Computed sags should be accurate to 3 mm (if in feet, to two decimal places) regardless of the method used.

Sag and tension data can be divided into three categories according to the physical state of the conductor, with reference to its past and present degree of stressing, and the length of time the conductor has been under stress. These three categories are referred to as: (1) initial loading condition, (2) final loading condition, and (3) final loading condition with creep.

(1) The initial loading condition applies to conductors which have not been stressed beyond a small percentage of the stress value selected as the maximum operating stress. Sags based on this condition are used as stringing data for unstressed conductors, and as basic data for preparing sag templates, which are used to determine uplift forces on structures. Tensions are used to determine maximum stress conditions.

(2) The final loading condition applies to conductors which have been stressed to the value selected as the maximum operating stress, but where the conductor has been under this stress for only a short time. Sags and tensions based on this condition are used to determine the full-load sag and tension, and stringing data for prestressed conductors. Tensions are used to determine maximum stress conditions.

(3) The final loading condition with creep applies to conductors which have been in place for several years. Creep values are generally based on a 10-year period, since about 95 percent of the creep has been removed from the conductor over this length of time. Sags based on this loading condition are used for preparing sag templates that can be used for spotting structures on plan-profile drawings. Corresponding tensions are used in broken conductor calculations.

Sag and tension values for a given span length and conductor will vary according to the loading conditions, that is, the sag for the final loading condition with creep will be greater than the sag for the final loading condition, and the sag for the final loading condition will be greater than the sag for the initial loading condition. The difference in the sag between final loading with creep and the final loading conditions is obviously due to creep. The value of this creep is dependent on the magnitude of the average tension and the length of time the tension has been applied. The difference in the sag between final and initial loading conditions is due to permanent set. The value of the permanent set is dependent upon the magnitude of the maximum stress attained by the conductor. To compute sags and tensions based on initial loading conditions, the initial modulus of elasticity for the conductor under study must be determined and used in formulas involving the modulus. Likewise, the final modulus of elasticity must be determined and used in order to compute sags and tensions based on either the final loading condition or the final loading condition with creep.

To relate initial conditions, final conditions, and final conditions with creep, values of creep and permanent set must be determined. To determine these values, the initial modulus may be taken as the slope of a straight line which most closely approximates the initial loading curve between the point of maximum stress and the point of zero stress. The final modulus is the slope of the unloading line. The permanent set may be taken as the difference in elongation at zero stress between the initial loading curve and the unloading line. In the case where the initial modulus is represented by a line approximating the initial loading curve, the permanent set may be taken as the difference in elongation at zero stress between the initial modulus line and the unloading line.

Whenever electrical conductors or overhead ground wires are strung above ground, they are subjected to the effects of wind, temperature, and ice, all of which add load to the wires. Standard loading conditions and recommendations for conductor tensions are set forth in NESC. These NESC rules have been adopted as the basic standard code requirements by all of the 17 Western States that the Bureau of Reclamation serves, except California. California has established its own code, which is published as the *Rules for Overhead Line Construction* [1].[1]

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[1] Numbers in brackets refer to items in the Bibliography.

The standard NESC loading conditions are *Light*, *Medium*, and *Heavy*, which apply in general to the loading districts of the United States as shown on the general loading map in section 25 of NESC[3]. According to NESC, the total load on a conductor shall be the resultant loading per unit length of the components of the vertical load per unit length (ice covered where specified) and the horizontal load per unit length due to a horizontal wind pressure on the projected area of the conductor (ice covered where specified), to which resultant has been added a constant that can be determined from table 1.

Table 1.–*NESC conductor loading constants (K)*

	Loading		
	Heavy	Medium	Light
Radial thickness of ice, mm (in)	13 (0.5)	6 (0.25)	0 (0)
Horizontal wind pressure, kPa (lb/ft^2)	0.191 52 (4)	0.191 52 (4)	0.430 92 (9)
Temperature, °C (°F)	-18 (0)	-9.4 (+15)	-1 (+30)
Constant *K* to be added to the resultant of all conductors, N/m (lb/ft)	4.3782 (0.30)	2.9188 (0.20)	0.7297 (0.05)

The State of California specifies heavy loading conditions of 13-mm (0.5-in) radial thickness of ice and 0.29 kPa (6 lb/ft^2) of wind pressure on the projected area of cylindrical surfaces at minus 18 °C (0 °F) for all parts of the State where the elevation exceeds 914 m (3000 ft) above sea level. Unlike the NESC, the California code does not require the addition of conductor loading constants. California light loading conditions of no ice and 0.38-kPa (8-lb/ft^2) wind pressure on the projected area of cylindrical surfaces at minus 4 °C (25 °F) are specified for all areas of the State where the elevation above sea level is 914 m or less. However, our experience has shown that ice and snow are likely to occur at elevations below 914 m in northern California; therefore, some Bureau lines in this part of the State are designed for NESC medium loading conditions. This loading is more practical for the expected weather conditions and exceeds the requirements of the California code.

In Montana and Wyoming, NESC medium loading is specified for most of the area covering these States. However, extremely low temperatures have been encountered in these states during the winter so we have revised, for Bureau use, these loading areas to NESC heavy loading as shown on figure 1 in section 2.

Both the NESC and California codes recommend that conductors and overhead ground wires be strung at tensions such that the final unloaded tension at 15.5 °C (60 °F) will not exceed 25 percent of the ultimate strength, and the initial unloaded tension at 15.5 °C will not exceed 35 percent of the ultimate strength. The NESC permits tensions under load that do not exceed 60 percent of the ultimate strength under maximum assumed loading. The California code limits maximum load to 50 percent of the ultimate strength under maximum assumed loading.

For ACSR conductors, the Aluminum Company of America recommends that the tension shall not exceed 50 percent of the ultimate strength under maximum loading conditions; and that the final unloaded tension shall not exceed 25 percent of the ultimate strength at minus 18 °C (0 °F) in NESC and California heavy loading districts, at minus 9.4 °C (15 °F) in NESC medium loading districts, and at minus 1 °C (30 °F) in NESC light loading districts. These tensions are substantially less than those recommended by the codes and result in considerably less damage to the conductor from vibration.

Several years ago, we installed steel overhead ground wires at a final unloaded tension of 25 percent of the ultimate strength at 15.5 °C (60 °F). Numerous breaks due to vibration occurred in one or more wires of the seven-wire strand at the supporting suspension clamps. Vibration problems also occurred with some of the conductors, so we now design for a maximum final unloaded tension of 25 percent of the ultimate strength of both high-strength steel overhead ground wires and conductors at the following temperatures:

District	*Temperature*	
	°C	(°F)
NESC heavy loading	-40	(-40)
NESC medium loading	-29	(-20)
NESC light loading	-18	(0)

When extra-high-strength steel is used for overhead ground wires, we design for a maximum final unloaded tension of 20 percent of the ultimate strength at the temperatures shown above for the different loading districts.

Bureau design criteria for conductors and overhead ground wires should be in accordance with the data shown on figure 1; note that there are four limiting conditions shown.

Although the ice and wind loadings prescribed by the codes are generally applicable for determining the loading conditions to be used in the design of a transmission line, specific climatic and weather conditions should be studied for each transmission line or group of lines. For example, on our North and South Dakota transmission lines, the crossarms were designed to support a vertical load due to 38 mm (1.5 in) of ice on the conductors, but no extra wind load for the excess ice above 13 mm (0.5 in) was considered as it did not seem probable that heavy icing and high winds would occur simultaneously.

Certain limitations regarding allowable sags, tensions, and span lengths are set forth in NESC and in various local safety codes. These codes or regulations should be reviewed to determine the applicable limitations which should not be exceeded, except by written permission from the proper authorities. In the following paragraphs, a general discussion is given concerning the various types of spans, and special span combinations, for which sag and tension data are likely to be required. References are given to various methods which are in general use for computing sags and tensions in such spans.

A perfectly level (symmetrical) span is infrequently found in practice since almost all spans are inclined (asymmetrical) to some degree. However, the level span problem lends itself to comparatively simple treatment by either the parabolic or catenary relations. Numerous methods have been derived for computing sags and tensions in level spans, the majority of which are based on catenary relations in the form of dimensionless ratios. Four of these methods are described in references [4, 5, 6, 7]. Reference [6] offers the greatest facility in most problems and is discussed further in the following section. Before using any method, a careful study should be made to determine the limitations of the method, and then care should be given to the application of the method within these limits.

As might be expected, the computation of sags and tensions for inclined spans is complicated by their asymmetry. Most inclined spans are supported by suspension or pin-type insulators at both ends, or by suspension or pin-type insulators at one end and by dead-end-type insulators at the other end. A few inclined spans may be dead-ended at both ends. Usually, the suspended type of inclined span can be designed by modifying or correcting the data computed for symmetrical spans. For structure spotting purposes, the ruling span sag template based on symmetrical spans usually may be used without correction. For extremely steep hillside spans, special calculations, such as extending the catenary curves to theoretical points of support at the same elevation as the upper support and then solving each sag condition as an individual level span, should be made to provide sag curves which can be used for determining proper conductor clearances to ground and to obstructions. Inclined spans dead-ended at both ends also require special treatment. A method which applies to this case is given as reference [5]. Inclined spans are further discussed in section 14.

The determination of sags and tensions in spans adjacent to a broken conductor is important in design work from the standpoint of assuring compliance under this condition with clearance requirements over railroad, highway, waterway, communication line, and powerline crossings; and from the standpoint of determining the unbalanced loads on the structures. The computation of sags and tensions under this condition is quite involved, due mainly to the many variables introduced. A method which applies directly to this problem is given as reference [8]. In addition to this published solution, an unpublished method was devised by Mr. G. R. Wiszneauckas, former Bureau engineer, that offers a margin of facility over other methods. This method has been included in this manual as appendix A, and an example problem using this method is shown in section 16.

In a series of suspension spans, where relatively short spans occur adjacent to a relatively long span, it is desirable to determine the changes in sags and tensions which would result from temperature and loading changes and from unbalanced loadings. In some cases, such changes or unbalances will produce dangerous loads on the structures; in others, clearances may be reduced below the required values. The nature of this problem is very similar to that of the broken conductor problem; consequently, most of the methods for handling the broken conductor problem can be applied to this problem with slight modification. An example problem on unbalanced conditions is presented in section 16.

Problems relating to spans with concentrated loads are relatively few and are confined mainly to substation or switchyard approach spans in which *taps* or *tie-down* arrangements are used. Such problems are complicated by the elastic effects of the tie-down in addition to the dead load applied. No published method is known which adequately treats this problem; however, a method was devised by the Bureau that handles this problem with facility, see section 18.

Another problem similar to spans with concentrated loads appears in the use of extremely short dead-ended spans with long insulator strings. This problem may be handled by use of the methods in references [5, 10, 11]. Problems where the concentrated load consists of dead load only can be handled by one of the methods given in reference [12].

12. Sag and Tension Calculations Using Copperweld Sag Calculating Charts.–*Martin's Sag Calculating Tables* [4] were first made public by Mr. James S. Martin in a paper he presented to the Engineers' Society of Western Pennsylvania in November 1922. In 1931, the tables were first published in book form by the Copperweld Steel Co. That first edition, and several editions since then, have been in constant use by engineers designing overhead transmission lines. Calculations of sags and tensions by Martin's Tables consist of filling out a calculation form by reading tables, interpolating, and computing values. There is a trial-and-error method required in the use of these tables.

The "Graphic Method for Sag-Tension Calculations", developed by Alcoa, is a system employing a series of correlated graphs to determine the sag and tension characteristics of an overhead conductor. Graphical methods are very satisfactory but require considerable time in preparing curves, superimposing graph upon graph, and reading values for various conditions.

The *Copperweld Sag Calculating Charts* [6] were developed to simplify the calculation of sags and tensions for overhead lines. The charts are based on the functions of the catenary as given in Martin's Tables. The general procedure for solving sag and tension problems using these charts is the same as with Martin's Tables. However, the charts provide a graphical relationship between unstressed length factors, elongation factors, and factors of SW/T (span length times the vertical force of the conductor divided by the tension) which eliminates the interpolating and the trial-and-error methods required when using the tables. The range of the charts covers most types of construction but, on occasion, it may be necessary to revert to Martin's Tables for part of the solution.

Designers using the charts and tables should be aware that all wire is elastic to some extent. When tension is applied to a wire, as is done when a conductor is strung between two supports, the wire stretches. If the tension in the wire increases, the length of the wire increases. With different amounts of load on a suspended wire, the elongation (stretch) and the tension in the wire will change.

A temperature change in the wire also changes its length. If the temperature changes while the wire is unstressed (at zero tension) and the wire is free to change its length, the length changes but there is no change in tension. When the wire is suspended in tension and the temperature changes, the change in length is affected by both the temperature change and the elastic characteristics of the wire. All changes due to ice, wind, and temperature are taken into consideration when computing sags and tensions in conductors by this method of charts and tables.

The conductor sag and tension calculation form is shown on figure 13. During the metric changeover period, we have both a metric and a U.S. customary form for our use. Figure 13 shows the metric form to which we have added item numbers to help explain the form:

	Item	Explanation
(1)	Conductor size	Determined from economic studies
(2)	Conductor code name[1]	
(3)	Rated breaking strength[1]	
(4)	Diameter,[1] mm (in)	
(5)	Radial thickness of ice, mm (in)	From NESC or State codes
(6)	Wind, kPa (lb/ft^2)	From NESC or State codes
(7)	Loading	From NESC or State codes
(8)	W', N/m (lb/ft)	Vertical force (weight) of conductor[1]
(9)	W'', N/m (lb/ft)	Vertical force (weight) of conductor with ice[1] (if applicable)
(10)	Wind, N/m (lb/ft)	Force of wind on conductor and ice[1] (if applicable)
(11)	W''', N/m (lb/ft)	Resultant force, including applicable constant if NESC loading[1]
(12)	Area A, mm^2 (in^2)	Cross sectional area of conductor[1]
(13)	Temperature coefficient of linear expansion	Change in length of conductor due to temperature change[1]

	Item	Explanation
(14)	Final modulus *E*, GPa (lb/in^2)	Slope of final (unloading) curve of stress-strain diagram[1]
(15)	Initial modulus *E*, GPa (lb/in^2)	Slope of initial loading curve of stress-strain diagram[1] (average slope between maximum loading and point where entire conductor starts to assume loading)
(16)	Final *AE*, N (lb)	Product of conductor area (12) and final modulus (14)
(17)	Initial *AE*, N (lb)	Product of conductor area (12) and initial modulus (15)
(18)	Span length, m (ft)	Length of span for which computations are to be made
(19)	Thickness of ice, mm (in); and force of wind, kPa (lb/ft^2)	For full-load condition
(20)	Temperature, °C (°F)	For full-load condition
(21)	Tension, N (lb), initial	Expected or desired tension at full-load conditions (Must not exceed 50 percent of ultimate strength of conductor. May be limited by 33-1/3 percent of ultimate strength of conductor for no-load initial conditions, or 25 percent of conductor ultimate strength for no-load final conditions. At temperatures indicated on fig. 1).
(22)	*SW*, N (lb) (two decimal places)	Span length (18) times resultant force per unit length of conductor (11)
(23)	*SW/T* (four decimal places)	*SW* (22) divided by full-load tension (21)
(24)	*SW/AE* (seven decimal places)	*SW* (22) divided by initial *AE* (17)
(25)	Unstressed length (six decimal places)	From Copperweld charts [6] at intersection of *SW/T* (23) and *SW/AE* (24) values
(26)	Permanent set and creep[1] (six decimal places)	
(27)	Unstressed length at -18 °C (0 °F) (six decimal places)	If value of unstressed length is for initial condition, then only a change for temperature, number of degrees change times temperature coefficient of linear expansion (13), need be made. However, if the value for unstressed length is to be for the final condition, then it will also be necessary to add the permanent set and creep to the value of unstressed length (25)
(28) - (31)	Unstressed length (six decimal places)	Change in value is equal to the degrees of temperature change times temperature coefficient of linear expansion (13)

Item		Explanation
(32)	*SW*, N (lb) (two decimal places)	Span length (18) times unloaded conductor force per unit length of conductor (8)
(33)	*SW*/*AE* (seven decimal places)	*SW* (32) divided by final *AE* (16)
(34) - (38)	*SW*/*T* (four decimal places)	From Copperweld charts [6] at intersections of unstressed length values (27) - (31) and *SW*/*AE* (33)
(39) - (44)	Sag factors (interpolate to five decimal places)	From table at back of Copperweld charts book [6], sag factor for each value of *SW*/*T* (23) and (34) - (38)
(45) - (50)	Sags, mm (ft) (two decimal places, if in feet)	Span length (18) times sag factors (39) - (44)
(51) - (55)	Tensions, N (lb)	*SW* (22) and (32) divided by *SW*/*T* (23) and (34) - (38), respectively

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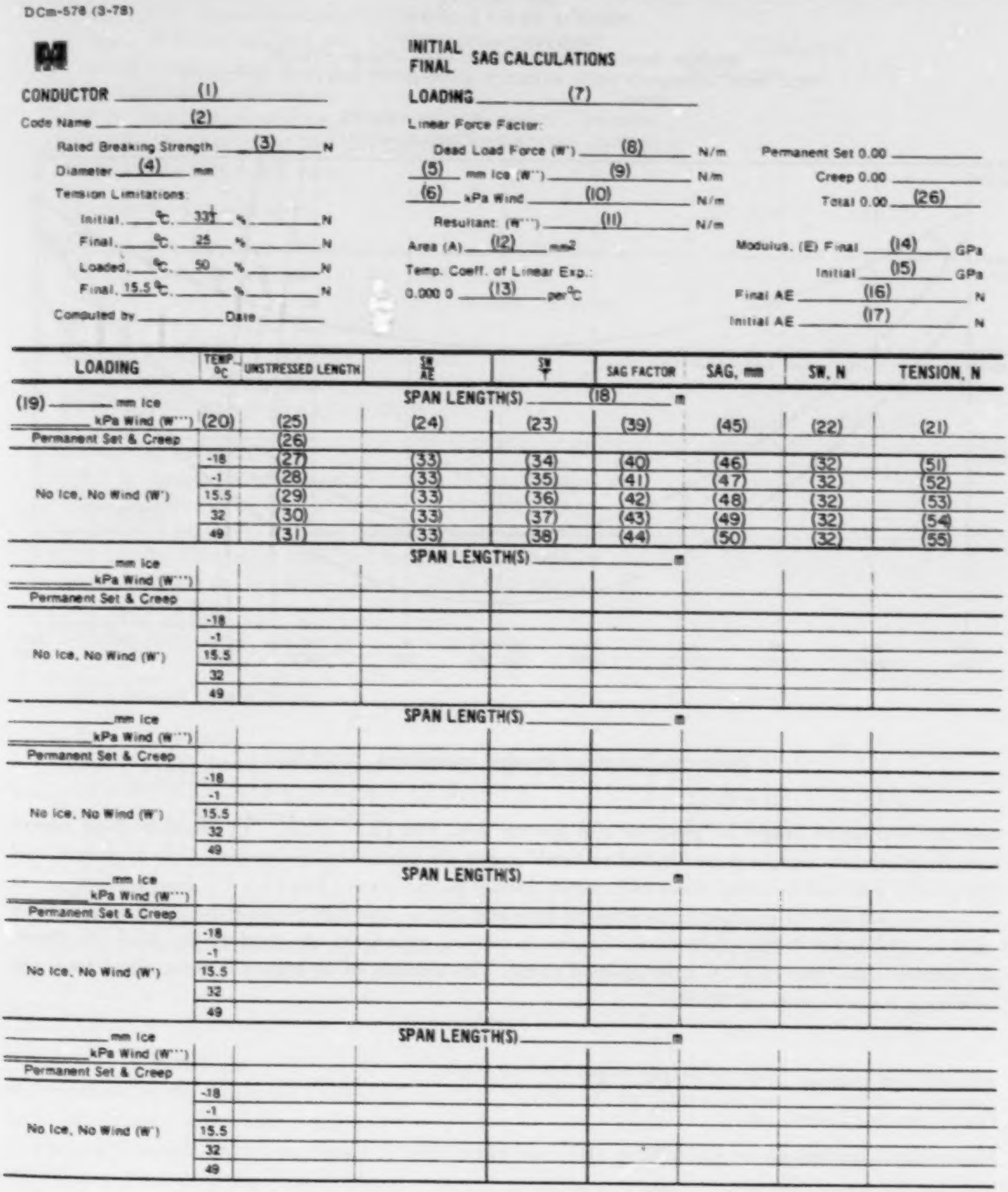
[1] Available from manufacturers' catalogs or data in appendixes.

Figure 13 can be used for any combination of ice, wind, and temperature conditions to find the resulting sags and tensions in a conductor. The procedure is the same for all cases, but one must be sure of the basic data and to keep in mind whether initial or final conditions are being computed.

13. Preparation of Sag Template.–If sag values for a conductor at a specified ruling span and for a specified loading are expanded to give corresponding values of sag at shorter and longer span lengths, and the resulting sag values plotted against the corresponding span lengths–a conductor profile curve results. When this curve is plotted to the same scale as a transmission line plan-profile survey drawing, it is commonly called a *sag template* and can be used to facilitate the spotting or locating of structures on plan-profile drawings. The data required to prepare a sag template are the sag and tension values of the conductor at the ruling span length for the temperature and loading conditions desired. These basic sag values can be computed and extended to corresponding values for shorter and longer span lengths by either the parabolic or catenary relations, or by any of the methods shown in this chapter. Whatever method used should be governed by the limitations of that method. The tension values corresponding to the sag values of the ruling span are required only to compute catenary parameters, which must be known in order to expand the basic sag values by the catenary relations. The template is made on a transparent sheet of plastic approximately 254- by 356- by 0.635-mm (10- by 14- by 0.025-in) size. The template, made to the same scales that were used for plotting the plan-profile sheets, represents the conductor profile curve at 15.5 °C (60 °F), and also a curve at an assumed minimum temperature. A maximum temperature curve, usually taken at 49 °C (120 °F) or 54 °C (130 °F), may also be drawn on the template, if desired, for checking maximum sags. The minimum temperature curve may be drawn for any temperature between minus 1 °C (30 °F) and minus 51 °C (–60 °F), depending on locality and climatic conditions. The minimum temperature curve is plotted from initial sag values, and the other curves are plotted from final sag values. Figure 14 shows a sag template prepared for a specific conductor under specific loading conditions. Changing any of these specified conditions would change the shape of the curves,



DCm-578 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR ____(1)____

Code Name ____(2)____

Rated Breaking Strength ____(3)____ N

Diameter ____(4)____ mm

Tension Limitations:

Initial, ____ °C, 33⅓ % ________ N

Final, ____ °C, 25 % ________ N

Loaded, ____ °C, 50 % ________ N

Final, 15.5 °C, ____ % ________ N

Computed by ________ Date ________

LOADING ____(7)____

Linear Force Factor:

Dead Load Force (W') ____(8)____ N/m

(5) mm Ice (W'') ____(9)____ N/m

(6) kPa Wind ____(10)____ N/m

Resultant: (W''') ____(11)____ N/m

Area (A) ____(12)____ mm²

Temp. Coeff. of Linear Exp.:

0.000 0 ____(13)____ per °C

Permanent Set 0.00 ________

Creep 0.00 ________

Total 0.00 ____(26)____

Modulus, (E) Final ____(14)____ GPa

Initial ____(15)____ GPa

Final AE ____(16)____ N

Initial AE ____(17)____ N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
			SPAN LENGTH(S) ____(18)____ m					
(19) ______ mm Ice ______ kPa Wind (W''')	(20)	(25)	(24)	(23)	(39)	(45)	(22)	(21)
Permanent Set & Creep		(26)						
No Ice, No Wind (W')	-18	(27)	(33)	(34)	(40)	(46)	(32)	(51)
	-1	(28)	(33)	(35)	(41)	(47)	(32)	(52)
	15.5	(29)	(33)	(36)	(42)	(48)	(32)	(53)
	32	(30)	(33)	(37)	(43)	(49)	(32)	(54)
	49	(31)	(33)	(38)	(44)	(50)	(32)	(55)
			SPAN LENGTH(S) ________ m					
______ mm Ice ______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							
			SPAN LENGTH(S) ________ m					
______ mm Ice ______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							
			SPAN LENGTH(S) ________ m					
______ mm Ice ______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							
			SPAN LENGTH(S) ________ m					
______ mm Ice ______ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							

Figure 13.–Explanation of standard sag and tension calculation form.

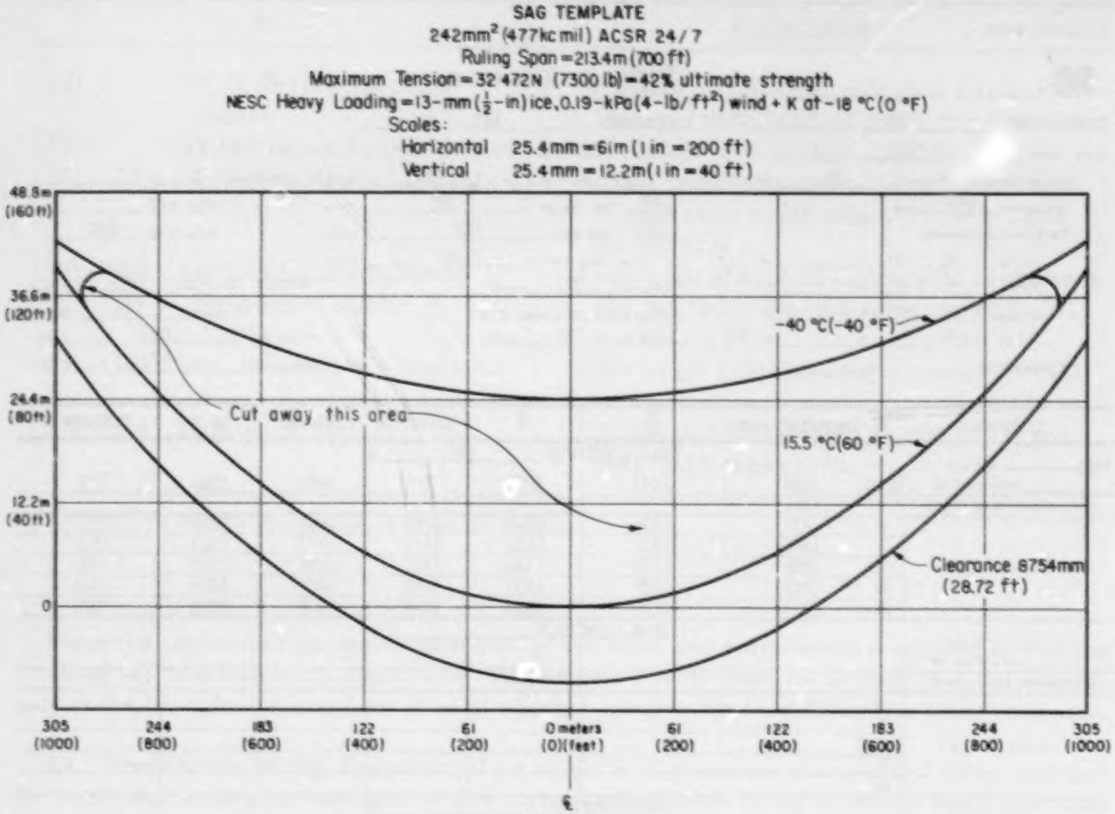


Figure 14.–Typical sag template construction. 104-D-1054.

and they would no longer be good for this specific job. The 15.5 °C (60 °F) "final no-load" curve and the minimum temperature "initial no-load" curve are plotted in the center of the template, and the plastic material between these two curves should be cut away. The 15.5 °C final no-load curve is used for plotting the conductor location on plan and profile drawings because this is the temperature used as a basis for NESC clearances. Clearance curves, which are identical to the 15.5 °C curve, are drawn below the 15.5 °C final no-load curve. The amount of clearance is determined from the following requirements of NESC:

Assume line voltage	115 kV
Plus 5 percent overvoltage	5.75
Maximum line voltage	120.75 kV
Line to ground = $\frac{120.75}{\sqrt{3}}$	69.7 kV

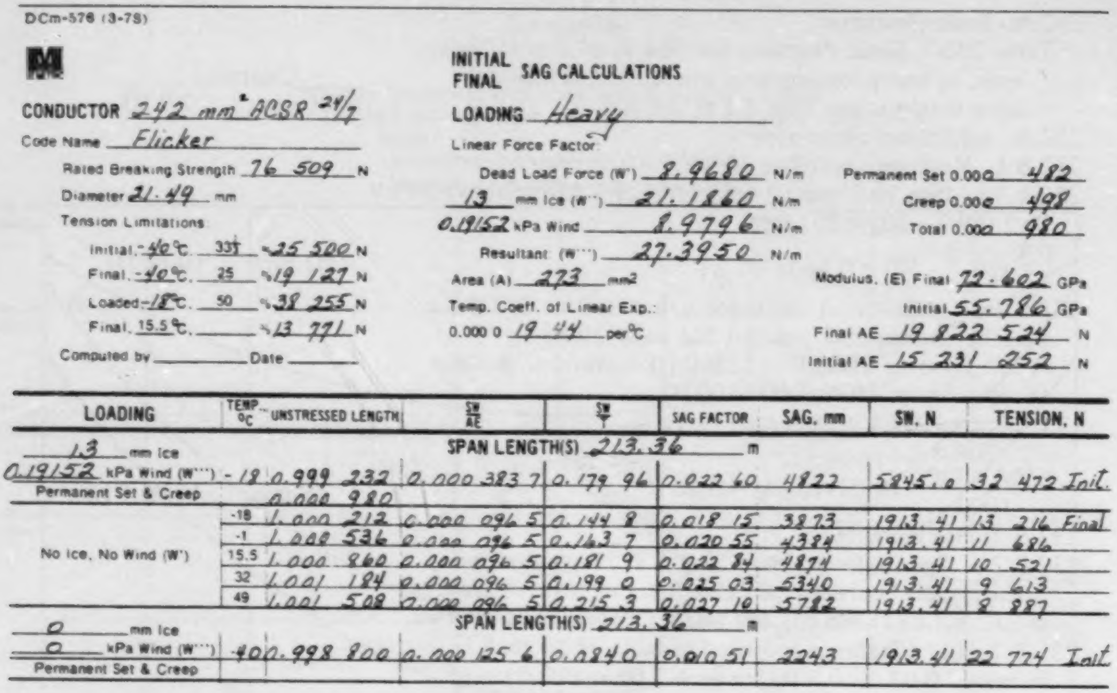
Assume 213.4-m (700-ft) ruling span.
Clearance from NESC, 1977 edition, Rule 232:

	Clearance	
232.A. Basic clearance		
Table 232-1, Basic clearance for 50-kV, 53.3-m (175-ft) span, in heavy loading area where equipment operating height is less than 4.3 m (14 ft)	6706 mm	(22.0 ft)
232.B. Additional clearances		
232.B.1. Voltages exceeding 50 kV		
232.B.1.a. Plus 10.2 mm (0.4 in) for each kilovolt above 50 kV		
$10.2\,(69.7 - 50) = 201$ mm		
$\frac{0.4}{12}\,(69.7 - 50) = 0.66$ ft	201 mm	(0.66 ft)
232.B.1.b. Additional clearance calculated in 232.B.1.a. shall be increased 3 percent for each 304.8 m (1000 ft) over 1005.8-m (3300-ft) elevation. Assume an elevation of 1920.2 m (6300 ft):		
$\frac{1920.2 - 1005.8}{304.8}\,(0.03)\,(201) = 18$ mm		
$\frac{6300 - 3300}{1000}\,(0.03)\,(0.66) = 0.06$ ft	18 mm	(0.06 ft)
232.B.2. Sag increase		
232.B.2.c. Span is longer than 53.3 m (175 ft). Assume line operates below 49 °C (120 °F). Calculate clearances in 232.B.2.c.(1) and (3), use smaller clearance of the two.		
232.B.2.c.(1) Clearance specified in table 232-1 shall be increased 0.03 m (0.1 ft) for each 3.05 m (10 ft) over 53.3 m (175 ft).		
$\frac{213.4 - 53.3}{3.05}\,(0.03) = 1.57$ m		
$\frac{700 - 175}{10}\,(0.1) = 5.25$ ft		
232.B.2.c.(3) Limits		
Assume difference in final sag at 15.5 °C (60 °F), no wind, and 49 °C (120 °F), no wind = 1.2 m (4 ft)	1219 mm	(4.0 ft)
Total clearance required by NESC	8144 mm	(26.72 ft)
6706 + 201 + 18 + 1219 = 8144 mm		
22 + 0.66 + 0.06 + 4 = 26.72 ft		
Plus, for width of profile line on drawing and small errors in plotting	610 mm	(2.0 ft)
Total ground clearance on sag template	8754 mm	(28.72 ft)

For lines in California, a 54 °C (130 °F) final no-load curve should be used for the sag template and for locating the structures instead of the 15.5 °C (60 °F) final no-load curve. Clearances should be in accordance with reference [1].

The sag template shown on figure 14 was made from the data indicated on the sag and tension calculation sheets, figures 15 and 16:

15.5 °C (60 °F), final, no-load sag for 213.4-m (700-ft) ruling span = 4874 mm (15.99 ft)
Minus 40 °C (–40 °F) initial, no-load sag for 213.4-m ruling span = 2243 mm (7.36 ft)



DCm-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

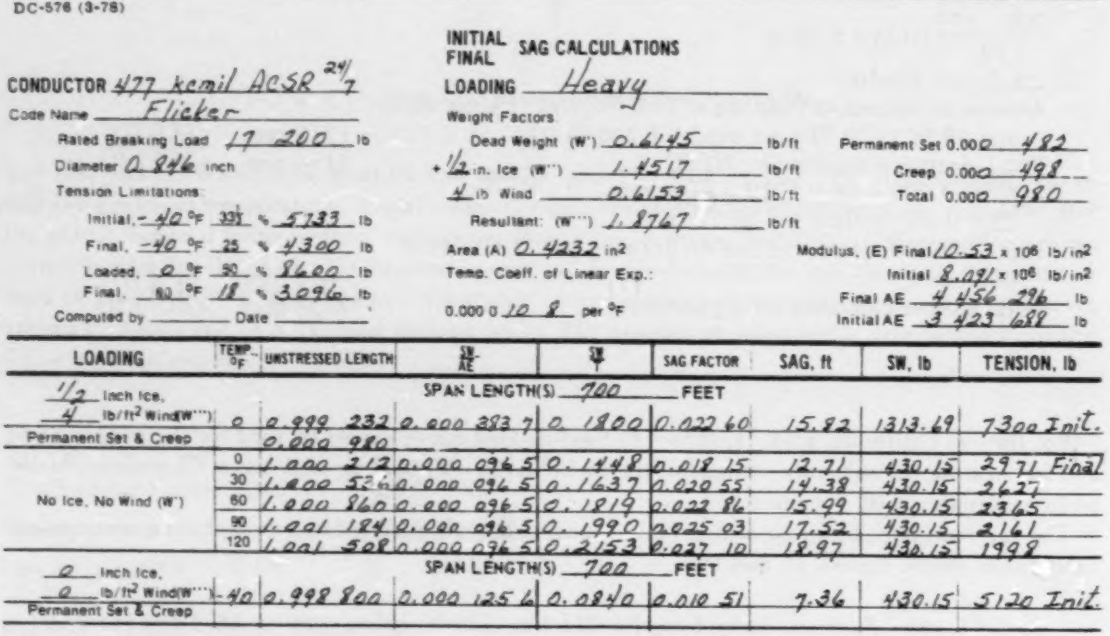
CONDUCTOR 242 mm² ACSR 24/7
Code Name Flicker
Rated Breaking Strength 76 509 N
Diameter 21.49 mm
Tension Limitations:
Initial, -40°C, 33⅓ % 25 500 N
Final, -40°C, 25 % 19 127 N
Loaded, -18°C, 50 % 38 255 N
Final, 15.5°C, % 13 771 N
Computed by ________ Date ________

LOADING Heavy
Linear Force Factor:
Dead Load Force (W') 8.9680 N/m
13 mm Ice (W'') 21.1860 N/m
0.19152 kPa Wind 8.9796 N/m
Resultant (W''') 27.3950 N/m
Area (A) 273 mm²
Temp. Coeff. of Linear Exp.:
0.000 0 19 44 per °C

Permanent Set 0.000 482
Creep 0.000 498
Total 0.000 980
Modulus, (E) Final 72.602 GPa
Initial 55.786 GPa
Final AE 19 822 524 N
Initial AE 15 231 252 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
13 mm Ice	SPAN LENGTH(S) 213.36 m							
0.19152 kPa Wind (W''')	-18	0.999 232	0.000 383 7	0.179 96	0.022 60	4822	5845.0	32 472 Init.
Permanent Set & Creep		0.000 980						
No Ice, No Wind (W')	-18	1.000 212	0.000 096 5	0.144 8	0.018 15	3873	1913.41	13 216 Final
	-1	1.000 536	0.000 096 5	0.163 7	0.020 55	4384	1913.41	11 686
	15.5	1.000 860	0.000 096 5	0.181 9	0.022 84	4874	1913.41	10 521
	32	1.001 184	0.000 096 5	0.199 0	0.025 03	5340	1913.41	9 613
	49	1.001 508	0.000 096 5	0.215 3	0.027 10	5782	1913.41	8 887
0 mm Ice	SPAN LENGTH(S) 213.36 m							
0 kPa Wind (W''')	40	0.998 800	0.000 125 6	0.0840	0.010 51	2243	1913.41	22 774 Init.
Permanent Set & Creep								

Figure 15.–Sag and tension calculation form for example problem on sag template (metric).



DC-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

CONDUCTOR 477 kcmil ACSR 24/7
Code Name Flicker
Rated Breaking Load 17 200 lb
Diameter 0.846 inch
Tension Limitations:
Initial, -40 °F 33⅓ % 5733 lb
Final, -40 °F 25 % 4300 lb
Loaded, 0 °F 50 % 8600 lb
Final, 60 °F 18 % 3096 lb
Computed by ________ Date ________

LOADING Heavy
Weight Factors
Dead Weight (W') 0.6145 lb/ft
+ 1/2 in. Ice (W'') 1.4517 lb/ft
4 lb Wind 0.6153 lb/ft
Resultant: (W''') 1.8767 lb/ft
Area (A) 0.4232 in²
Temp. Coeff. of Linear Exp.:
0.000 0 10 8 per °F

Permanent Set 0.000 482
Creep 0.000 498
Total 0.000 980
Modulus, (E) Final 10.53 x 10⁶ lb/in²
Initial 8.091 x 10⁶ lb/in²
Final AE 4 456 296 lb
Initial AE 3 423 688 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
1/2 Inch Ice,	SPAN LENGTH(S) 700 FEET							
4 lb/ft² Wind (W''')	0	0.999 232	0.000 383 7	0.1800	0.022 60	15.82	1313.69	7300 Init.
Permanent Set & Creep		0.000 980						
No Ice, No Wind (W')	0	1.000 212	0.000 096 5	0.1448	0.018 15	12.71	430.15	2971 Final
	30	1.000 536	0.000 096 5	0.1637	0.020 55	14.38	430.15	2627
	60	1.000 860	0.000 096 5	0.1819	0.022 86	15.99	430.15	2365
	90	1.001 184	0.000 096 5	0.1990	0.025 03	17.52	430.15	2161
	120	1.001 508	0.000 096 5	0.2153	0.027 10	18.97	430.15	1998
0 Inch Ice,	SPAN LENGTH(S) 700 FEET							
0 lb/ft² Wind (W''')	-40	0.998 800	0.000 125 6	0.0840	0.010 51	7.36	430.15	5120 Init.
Permanent Set & Creep								

Figure 16.–Sag and tension calculation form for example problem on sag template (U.S. customary).

Using the relationship from section 8,

$$\frac{Sag_{RS}}{(RS)^2} = \frac{Sag_1}{(Span_1)^2}$$

where,

Sag_{RS} = sag in ruling span, mm (in)
Sag_1 = sag in any other given span, mm (in)
RS = ruling span length, m (ft)
$Span_1$ = span length of any other given span, m (ft)

$$\text{For 15.5 °C final:}\quad \frac{Sag_{RS}}{(RS)^2} = \frac{4.874\text{ m}}{(213.36\text{ m})^2} = 1.0707 \times 10^{-4}\,\text{m}^{-1} = K_1$$

$$\text{60 °F final:}\quad \frac{Sag_{RS}}{(RS)^2} = \frac{15.99\text{ ft}}{(700\text{ ft})^2} = 3.2633 \times 10^{-5}\,\text{ft}^{-1} = K_1$$

$$\text{For -40 °C initial:}\quad \frac{Sag_{RS}}{(RS)^2} = \frac{2.243\text{ m}}{(213.36\text{ m})^2} = 4.9272 \times 10^{-5}\,\text{m}^{-1} = K_2$$

$$\text{-40 °F initial:}\quad \frac{Sag_{RS}}{(RS)^2} = \frac{7.36\text{ ft}}{(700\text{ ft})^2} = 1.502 \times 10^{-5}\,\text{ft}^{-1} = K_2$$

Assume values for span lengths (x), square these (x^2), and multiply by the K values to obtain the sags as shown in table 2.

Table 2.–*Calculations for sag template*

Span length x		(Span length)^2 x^2		15.5 °C (60 °F) Sag K_1x^2			−40 °C (−40 °F) Sag K_2x^2		
m	ft	m^2	ft^2	m	mm	ft	m	mm	ft
60.96	200	3 716.12	0.4×10^5	0.398	398	1.31	0.183	183	0.60
121.92	400	14 864.49	1.6×10^5	1.592	1 592	5.22	0.732	732	2.40
243.84	800	59 457.95	6.4×10^5	6.366	6 366	20.89	2.930	2 930	9.61
365.76	1200	133 780.38	14.4×10^5	14.324	14 324	46.99	6.592	6 592	21.63
487.68	1600	237 831.78	25.6×10^5	25.464	25 464	83.54	11.718	11 718	38.45
609.60	2000	371 612.16	40.0×10^5	39.788	39 788	130.53	18.310	18 310	60.08

Using the same scales as those used on the plan-profile sheets (25.4 mm = 61 m or 1 in = 200 ft horizontally, and 25.4 mm = 12.2 m or 1 in = 40 ft vertically), plot the sag values on the sag template for the span lengths shown in table 2. The curves should be expanded far enough on the sag template to permit its use on an entire transmission line, with the possible exception of an extremely steep span where a special catenary curve should be used.

Draw a vertical line at the center of the template (zero span length) for a reference line. This line must be kept perfectly vertical when the template is being used for laying out a transmission line.

Clearance (conductor to earth) curves should be located at the specified NESC distances below the 15.5 °C (60 °F) final sag curve. The clearance curves will be identical to the final sag curve but will be offset vertically from it by the values of clearance required.

All curves should be identified on the sag template. The conductor size and type, the ruling span, maximum conductor tension, NESC loading, and the horizontal and vertical scales used should also be noted on the template.

14. Inclined Spans.–In practice, nearly every span of a transmission line is inclined (asymmetrical) to some degree. As might be suspected, the computations for sags and tensions for inclined spans may get rather complex, depending upon the degree of their asymmetry. In general, inclined spans may be classified into two categories for design purposes: (1) inclined spans supported by suspension or pin-type insulators at both ends of the span, and inclined spans supported by suspension or pin-type insulators at one end of the span and by dead-end type insulators at the other end; and (2) inclined spans which are dead-ended at both ends. Problems concerning inclined spans falling in the first category usually can be handled by modifying or correcting data computed for symmetrical spans. For structure layout or spotting purposes, the ruling span sag template based on symmetrical spans usually may be used without correction. Inclined spans dead-ended at both ends require special treatment, even for layout or spotting purposes, if they are fairly long spans and are located on extremely steep inclines. A series of spans located on extremely steep inclines may require insulator offset calculations for stringing purposes in order to get each successive span properly sagged (sec. 30(b), ch. V).

The method used for calculating sags and tensions for a dead-ended, inclined span depends somewhat on the steepness of the span. Some methods of calculation are good for all dead-ended spans, from level to almost vertical, while other methods apply to particular areas between these extremes.

For a dead-ended span of normal length and a relatively small incline, the calculations for a level span with the same horizontal distance between supports may be used. Using the notation shown on figure 17, the sag *D* (for this case) is measured vertically and is the vertical distance between the straight line joining the supports and a parallel line which is tangent to the conductor's curvature.

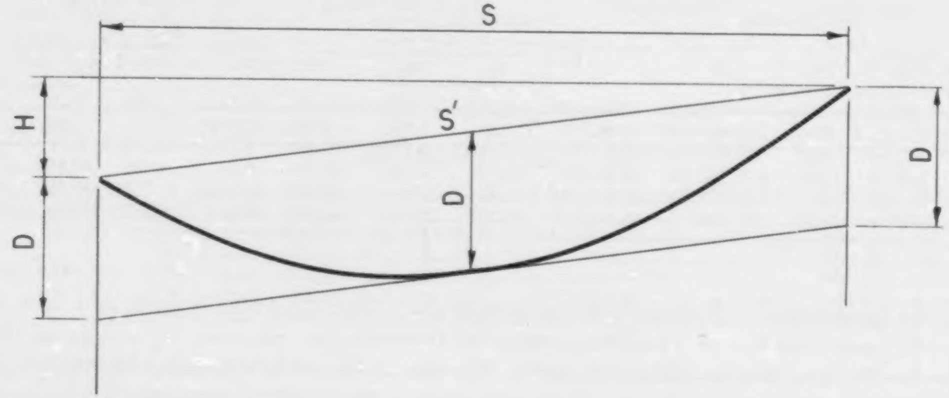


Figure 17.–Sag on inclined span–equivalent span method.

If the span is long, or if there is a relatively large difference in elevation of the end supports, some correction should be made in the calculations. Calculations based on the catenary are preferred over those based on the parabola because the conductor conforms to a catenary curve when suspended between supports—the steeper the span, the greater the difference between the comparable portion of a catenary and a parabola. In computing the sag, there is some error in assuming D to be the same as the sag for a level span of the same horizontal distance between supports. However, this can be minimized by using an *equivalent* level span. This method, although an approximation, gives results which are as accurate as can ordinarily be used in the field and within field limitations.

The equivalent span is taken as the slope span plus the difference between the slope span and the level span. Thus, the equivalent span equals $S' + (S' - S) = 2S' - S$. The sag D for the equivalent span is then calculated in the usual manner. This method may be used with less than 1 percent error for spans with an incline up to 20 percent.

Another method, which gives good results, uses an average tension in the span and has a corrected sag value. Using the notation shown on figure 18:

$$L_1 = \sqrt{L^2 + H^2}$$

$$T_1 - T_2 = wH$$

where w is the conductor linear force factor per unit length.

$$T_{av} = \frac{T_1 + T_2}{2} = \frac{2T_1 - wH}{2}$$

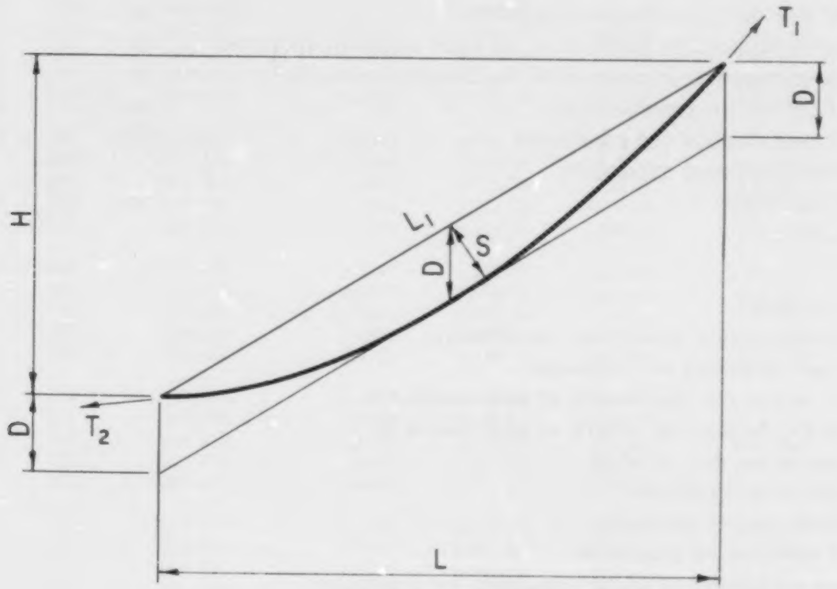


Figure 18.–Sag on inclined span–average tension method.

Use T_{av} and length L_1 to calculate sags and tensions for various conditions using Copperweld, Alcoa, or other acceptable methods. Correct the calculated sag by the relationship $D = SL_1/L$.

A method originally intended for calculating sags and tensions in steeply inclined spans, but which is applicable to spans of any incline, was developed by Mr. D. O. Ehrenburg while he was a member of the Bureau of Reclamation staff. For a full discussion of his method, including derivations of formulas, see reference [5]. A brief version of this method follows showing nonmenclature, formulas, procedure, and a sample calculation. Since the method is based on a parameter Z, the functions of Z are included as table 3.

Nomenclature and units

	Metric	*U.S. customary*
T_1 = tension at upper support	N	(lb)
T_e = effective (average) tension of conductor	N	(lb)
w = linear force factor of conductor per unit length	N/m	(lb/ft)
h = wind load per unit length of conductor	N/m	(lb/ft)
v = ice load per unit length of conductor	N/m	(lb/ft)
$w' = \sqrt{(w+v)^2 + h^2}$ = resultant force per unit length of conductor	N/m	(lb/ft)
S = actual length of conductor	m	(ft)
S_0 = unstressed length of conductor	m	(ft)
a = horizontal spacing of supports	m	(ft)
b = vertical spacing of supports	m	(ft)
c = straight line distance between supports	m	(ft)
a' = spacing of supports in plane of w', at right angles to vector w'	m	(ft)
b' = spacing of supports in plane of w', in direction of vector w'	m	(ft)
A = area of conductor cross section	mm^2	(in^2)
E = modulus of elasticity of conductor	GPa	(lb/in^2)
α = coefficient of linear expansion		
d = sag of conductor	mm	(ft)
Z = parameter		

Necessary given data:

Loading conditions (ice, wind, and temperature)
Size, type, and stranding of conductor
Linear force factor per unit length of bare conductor
Linear force factor per unit length of iced conductor
Force on conductor due to wind
Resultant force on conductor
Cross-sectional area of conductor
Modulus of elasticity of conductor
Temperature coefficient of linear expansion for conductor
Maximum tension in conductor
Horizontal spacing of supports
Vertical spacing of supports

Table 3.–*Functions of Z*

Z	$f(Z)$	coth Z	$1/Z$	Z^3	Z^4
0.010	0.000 016 67	100.003	100.000	0.000 001	0.000 000 01
.020	.000 066 6	50.007	50.000	.000 008	.000 000 16
.030	.000 150 0	33.343	33.333 3	.000 027	.000 000 81
.040	.000 266 7	25.013	25.000 0	.000 064	.000 002 56
.050	.000 416 7	20.017	20.000 0	.000 125	.000 006 25
.060	.000 600 1	16.687	16.666 7	.000 216	.000 012 96
.070	.000 816 9	14.309	14.285 7	.000 343	.000 024 01
.080	.001 067	12.527	12.500 0	.000 512	.000 040 96
.090	.001 351	11.141	11.111 1	.000 729	.000 065 61
.100	.001 668	10.0333	10.000 0	.001 000	.000 100 0
.110	.002 018	9.1275	9.090 9	.001 331	.000 146 4
.120	.002 402	8.3733	8.333 3	.001 728	.000 207 4
.130	.002 819	7.7356	7.692 3	.002 197	.000 285 6
.140	.003 270	7.1895	7.142 9	.002 744	.000 384 2
.150	.003 754	6.7166	6.666 7	.003 375	.000 506 3
.160	.004 272	6.3032	6.250 0	.004 096	.000 655 4
.170	.004 824	5.9389	5.882 4	.004 913	.000 835 2
.180	.005 409	5.6154	5.555 6	.005 832	.001 050
.190	.006 028	5.3263	5.263 2	.006 859	.001 303
.200	.006 680	5.0665	5.000 0	.008 000	.001 600
.205	.007 019	4.9462	4.878 05	.008 615	.001 766
.210	.007 366	4.8317	4.761 90	.009 261	.001 945
.215	.007 722	4.7226	4.651 16	.009 938	.002 137
.220	.008 086	4.6186	4.545 45	.010 648	.002 343
.225	.008 459	4.5192	4.444 44	.011 39	.002 563
.230	.008 840	4.4242	4.347 83	.012 17	.002 798
.235	.009 230	4.3334	4.255 32	.012 98	.003 050
.240	.009 628	4.2464	4.166 67	.013 82	.003 318
.245	.010 034	4.1630	4.081 63	.014 71	.003 603
.250	.010 449	4.0830	4.000 00	.015 63	.003 906
.255	.010 873	4.0062	3.921 57	.016 58	.004 228
.260	.011 305	3.9324	3.846 15	.017 58	.004 570
.265	.011 745	3.8615	3.773 58	.018 61	.004 932
.270	.012 194	3.7933	3.703 70	.019 68	.005 314
.275	.012 652	3.7276	3.636 36	.020 80	.005 719
.280	.013 118	3.6643	3.571 43	.021 95	.006 147
.285	.013 592	3.6033	3.508 77	.023 15	.006 598
.290	.014 076	3.5444	3.448 28	.024 39	.007 073
.295	.014 567	3.4876	3.389 83	.025 67	.007 573
.300	.015 068	3.4327	3.333 33	.027 00	.008 100
.305	.015 576	3.3797	3.278 69	.028 37	.008 654
.310	.016 094	3.3285	3.225 81	.029 79	.009 235
.315	.016 620	3.2789	3.174 60	.031 26	.009 846
.320	.017 154	3.2309	3.125 00	.032 77	.010 49
.325	.017 697	3.1845	3.076 92	.034 33	.011 16
.330	.018 249	3.1395	3.030 30	.035 94	.011 86
.335	.018 809	3.0959	2.985 07	.037 60	.012 59
.340	.019 378	3.0536	2.941 18	.039 30	.013 36
.345	.019 956	3.0126	2.898 55	.041 06	.014 17
.350	.020 542	2.9729	2.857 14	.042 88	.015 01

Table 3.–*Functions of Z*–Continued

Z	$f(Z)$	coth Z	$1/Z$	Z^3	Z^4
0.355	0.021 137	2.9343	2.816 90	0.043 74	0.015 88
.360	.021 740	2.8968	2.777 78	.046 66	.016 80
.365	.022 352	2.8603	2.739 73	.048 63	.017 75
.370	.022 973	2.8249	2.702 70	.050 65	.018 74
.375	.023 602	2.7905	2.666 67	.052 73	.019 78
.380	.024 240	2.7570	2.631 58	.054 87	.020 85
.385	.024 887	2.7245	2.597 40	.057 07	.021 97
.390	.025 543	2.6928	2.564 10	.059 32	.023 13
.395	.026 207	2.6620	2.531 65	.061 63	.024 34
.400	.026 880	2.6319	2.500 00	.064 00	.025 60
.405	.027 562	2.6027	2.469 14	.066 43	.026 90
.410	.028 252	2.5742	2.439 02	.068 92	.028 26
.415	.028 951	2.5464	2.409 64	.071 47	.029 66
.420	.029 659	2.5193	2.380 95	.074 09	.031 12
.425	.030 376	2.4929	2.352 94	.076 77	.032 63
.430	.031 102	2.4672	2.325 58	.079 51	.034 19
.435	.031 856	2.4421	2.298 85	.082 32	.035 81
.440	.032 579	2.4175	2.272 73	.085 18	.037 48
.445	.033 331	2.3936	2.247 19	.088 12	.039 21
.450	.034 092	2.3702	2.222 22	.091 13	.041 01
.455	.034 861	2.3474	2.197 80	.094 20	.042 86
.460	.035 640	2.3251	2.173 91	.097 34	.044 77
.465	.036 427	2.3033	2.150 54	.100 5	.046 75
.470	.037 223	2.2821	2.127 66	.103 8	.048 80
.475	.038 028	2.2613	2.105 26	.107 2	.050 91
.480	.038 842	2.2409	2.083 33	.110 6	.053 08
.485	.039 665	2.2210	2.061 86	.114 1	.055 33
.490	.040 497	2.2016	2.040 82	.117 6	.057 65
.495	.041 338	2.1826	2.020 20	.121 3	.060 04
.500	.042 188	2.1640	2.000 00	.125 0	.062 50

The loading conditions, conductor size, and maximum tension are determined by previous studies. All other conductor data required may be obtained from tables shown in appendix C or from manufacturers' catalogs. The horizontal and vertical spacing of supports can be determined from the plan-profile drawings.

Procedure steps:

1. Determine c from $c^2 = a^2 + b^2$
2. Determine b' from $b' = b(w + v)/w'$
3. Determine a' from $a' = \sqrt{c^2 - (b')^2}$

4. Determine coth Z from

$$\coth Z = \frac{\Delta}{1 + 0.167\left(\frac{a'}{c}\right)^2\left(\frac{1}{\Delta^2}\right)}$$

where:

$$\Delta = \frac{T_1'(\max) - 0.5\,w'b'}{0.5\,w'c}$$

For short spans,

$$Z = \frac{1}{\Delta} = \frac{0.5\,w'c}{T_1'(\max) - 0.5\,w'b'}$$

5. From table 3, determine Z from coth Z found in step 4
6. Determine S_0 from $S_0 = (S\text{-}c) + c$ where

$$S\text{-}c = \frac{a^2}{c}\,f(Z) + \frac{a^2 b^2}{72c^3}\,Z^4$$

Find $f(Z)$ from table 3 or from $f(Z) = 0.167(Z^2 + Z^4/20)$

7. Determine values for "No-load Chart"
   a. Assume values for Z (usually two values smaller and three or four values larger than the basic Z value found in step 5)
   b. Find S-c (from step 6) for each value of Z assumed in step 7.a.
   c. Determine S_0 (from step 6) for each assumed value of Z
   d. Determine values for T_1 and T_e by using the assumed values of Z in the formulas:

$$T_1 = 0.5\,w\,S_0\,\coth Z + 0.5\,wb, \text{ and } T_e = 0.5\,w\,S_0\left(\frac{1}{Z}\right) + 0.5\,w\,S_0\left(\frac{b^2}{3c^2}\right)Z$$

   e. Determine values for d from

$$d = 0.25\,cZ + \frac{3a^2 - 2b^2}{144c}\,Z^3 \text{ for assumed values of } Z$$

   f. Find the slope of the temperature lines from slope equals AE/S_0

8. Determine values for "Full-load Chart"
   a. Find S-c for each value of Z assumed in step 7.a., where

$$S\text{-}c = \frac{(a')^2}{c}\,f(Z) + \frac{(a')^2(b')^2}{72c^3}\,Z^4$$

   b. Determine S_0 for each assumed value of Z, where $S_0 = (S\text{-}c) + c$
   c. Determine horizontal spacing of the temperature lines from

$(S\alpha)$ (5.5), for increments of 5.5 °C from minus 7 to 48 °C, or
$(S\alpha)$ (10), for increments of 10 °F from 20 to 120 °F.

9. Prepare graph:

a. Plot the tensions for the assumed values of Z against the slack S-c. This will give four curves: T_1' and T_e' for full load, and T_1 and T_e for no load

b. Plot sag d against slack S-c on the same graph

c. Find the maximum average tension at full-load conditions by drawing a vertical line from the point of maximum tension on the full-load curve T_1' down to the full-load curve T_e'

d. Starting at the maximum average tension point found in step 9.c., draw temperature lines down to the no-load T_e curve. The slope of these lines was determined in step 7.e., and their horizontal spacing was found in step 8.b.

e. Determine the sag at every 5.5 °C from minus 7 to 48 °C or at every 10 °F from 20 to 120 °F by drawing vertical lines from the points where the temperature lines intersect the no-load T_e curve down to the sag curve

f. Label all parts of graph

Figure 19 shows the inclined span used for the following example calculations:

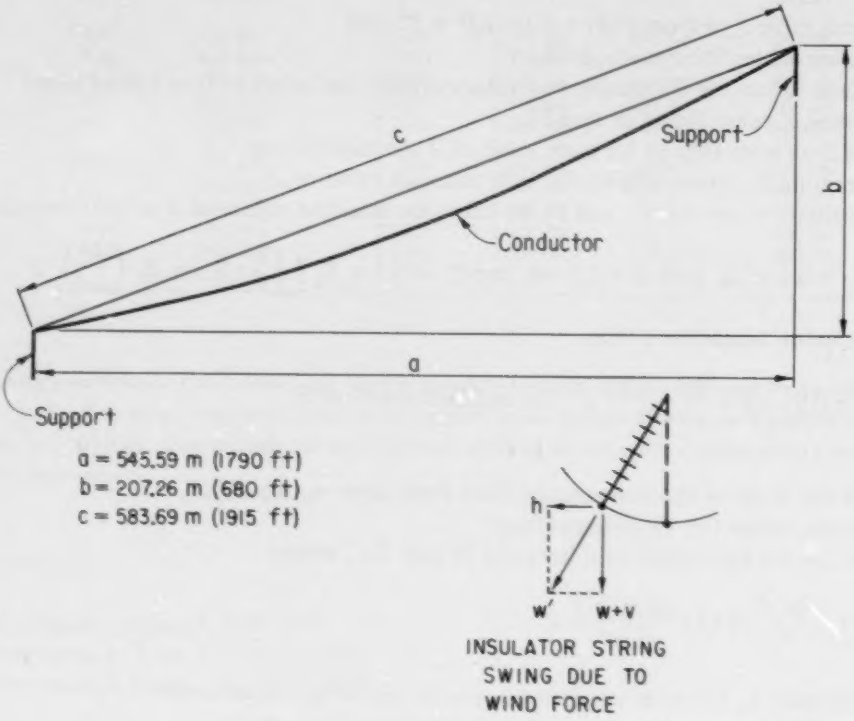

c
Support
b
Conductor
a
Support
a = 545.59 m (1790 ft)
b = 207.26 m (680 ft)
c = 583.69 m (1915 ft)
h
w'
w+v
INSULATOR STRING
SWING DUE TO
WIND FORCE

Figure 19.–Sag on inclined span–parameter Z method. 104-D-1055.

Example

Metric

Loading = 6-mm ice, 0.38-kPa wind, at minus 9.4 °C
Conductor = 1092 mm^2, ACSR 84/19 Bluebird
diameter = 45 mm
area = 1181 mm^2
$E = 51.46$ GPa (initial)
$\alpha = 0.000\,020\,7$ per °C
$w = 36.6453$ N/m
$h = (45 + 12)\,(0.38) = 21.66$ N/m
$v = 9.1314$ N/m
$w' = \sqrt{(36.6453 + 9.1314)^2 + (21.66)^2} = 50.64$ N/m
$a = 545.59$ m
$b = 207.26$ m
$c = 583.69$ m

$$b' = b\left(\frac{w+v}{w'}\right) = 207.26\left(\frac{36.6453 + 9.1314}{50.64}\right) = 187.36 \text{ m}$$

$$a' = \sqrt{c^2 - (b')^2} = \sqrt{(583.69)^2 - (187.36)^2} = 552.80 \text{ m}$$

$$\Delta = \frac{T_1'(\text{max}) - 0.5\,w'b'}{0.5\,w'c} = \frac{88\,964 - 0.5(50.64)\,(187.36)}{0.5(50.64)\,(583.69)} = 5.699$$

$$\Delta^2 = 32.479$$

$$\coth Z = \frac{\Delta}{1 + 0.167\left(\frac{a'}{c}\right)^2\left(\frac{1}{\Delta^2}\right)} = \frac{5.699}{1 + 0.167\left(\frac{552.80}{583.69}\right)^2\left(\frac{1}{32.479}\right)} = 5.6729$$

$Z = 0.17822$
$f(Z) = 0.005\,305$

$$S\text{-}c = \frac{a^2}{c}\,f(Z) + \frac{a^2b^2}{72c^3}\,Z^4 = \frac{(545.59)^2}{583.69}\,(0.005\,305) + \frac{(545.59)^2\,(207.26)^2}{72(583.69)^3}\,(0.178\,22)^4$$

$$= 2.7054 + 0.0009 = 2.7063$$

$$S_0 = (S - c) + c = 2.7063 + 583.69 = 586.40$$

For "No-Load Table"

$a = 545.59$
$b = 207.26$
$c = 583.69$
$w = 36.6453$

$0.5\,w = 18.3226$
$0.5\,wb = 3797.55$
$a^2/c = 509.98$
$a^2b^2/72c^3 = 0.8931$

$c/4 = 145.92$
$\dfrac{3a^2 - 2b^2}{144c} = 9.6023$
$b^2/3c^2 = 0.0420$

Z	0.16	0.17	0.1782	0.18	0.19	0.20	0.21
$S\text{-}c$	2.179	2.461	2.706	2.759	3.075	3.408	3.758
S_0	585.87	586.15	586.40	586.45	586.77	587.10	587.45
$0.5\,wS_0$	10 735	10 740	10 744	10 745	10 751	10 757	10 764
T_1	71 462	67 581	64 747	64 135	61 061	58 298	55 806
T_e	67 166	63 254	60 402	59 776	56 670	53 875	51 352
d	23.39	24.85	26.06	26.32	27.79	29.26	30.73

$AE/S_0 = 103\,640$

For "Full-Load Table"

$a' = 552.80$

$b' = 187.36$

$c = 583.69$

$w' = 50.64$

$0.5\,w' = 25.32$

$0.5\,w'b' = 4743.96$

$(a')^2/c = 523.54$

$(a')^2\,(b')^2/72c^3 = 0.7492$

$c/4 = 145.92$

$$\frac{3(a')^2 - 2(b')^2}{144c} = 10.07$$

$(b')^2/3c^2 = 0.0343$

Z	0.16	0.17	0.1782	0.18	0.19	0.20	0.21
$S\text{-}c$	2.237	2.526	2.778	2.833	3.157	3.498	3.858
S_0	585.93	586.22	586.47	586.52	586.85	587.19	587.55
$0.5\,wS_0$	14 836	14 843	14 849	14 851	14 859	14 868	14 877
T_1'	98 258	92 895	88 981	88 138	83 887	80 073	76 625
T_e'	92 806	87 399	83 459	82 598	78 303	74 442	70 950

$\Delta S = S\alpha(5.5) = 586.47(0.000\,020\,7)(5.5) = 0.066\,77$

Results of these metric calculations are shown on figure 20 along with initial sags for temperatures from minus 9.5 to 48 °C.

U.S. Customary

Loading = 1/4-in ice, 8-lb/ft² wind, at 15 °F

Conductor = 2156 kcmil, ACSR 84/19 Bluebird

diameter = 1.762 in

area = 1.8310 in²

$E = 7\,463\,320$ lb/in² (initial)

$\alpha = 0.000\,011\,5$ per °F

$w = 2.511$ lb/ft

$$h = \frac{1.762 + 0.5}{12}\,(8)\,(1) = 1.5080 \text{ lb/ft}$$

$\nu = 0.6257$ lb/ft

$$w' = \sqrt{(2.511 + 0.6257)^2 + (1.5080)^2} = 3.480 \text{ lb/ft}$$

$a = 1790$ ft

$b = 680$ ft

$c = 1915$ ft

$$b' = b\left(\frac{w+\nu}{w'}\right) = 680\left(\frac{3.1367}{3.480}\right) = 612.918 \text{ ft}$$

$$a' = \sqrt{c^2 - (b')^2} = \sqrt{(1915)^2 - (612.918)^2} = 1814.265 \text{ ft}$$

Temp. (°C)	Sag (m)
−9.5	24.8
−7.0	25.0
−1.5	25.35
4.0	25.65
9.5	25.95
15.0	26.2
20.5	26.5
26.0	26.8
31.5	27.1
37.0	27.4
42.5	27.65
48.0	27.9

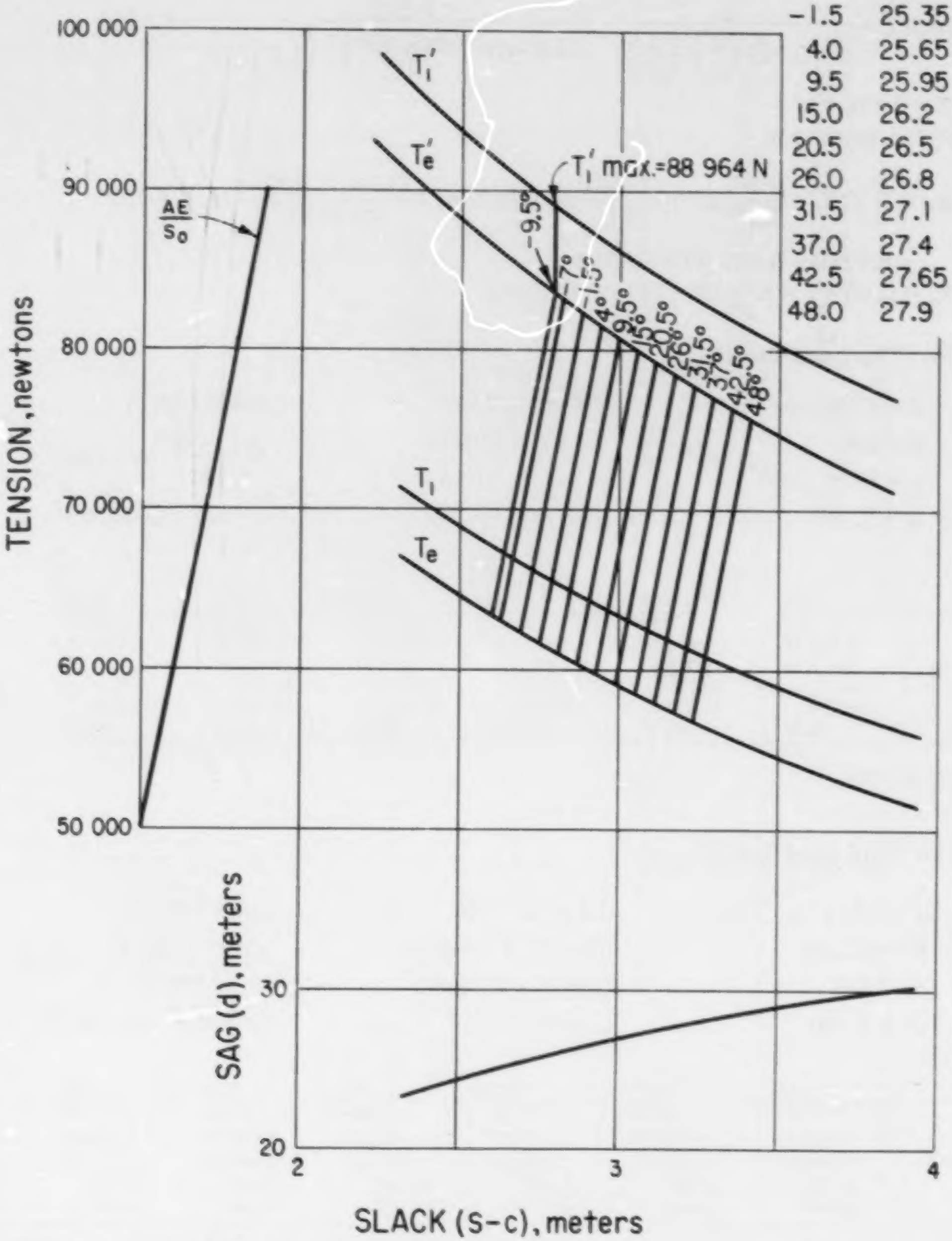


Figure 20.–Results of example problem on an inclined span using parameter Z method (metric). 104-D-1056.

$$\Delta = \frac{T_1'(\max) - 0.5\,w'b'}{0.5\,w'c} = \frac{20\,000 - 0.5(3.480)\,(612.918)}{0.5(3.480)\,(1915)} = 5.682$$

$$\Delta^2 = 32.286$$

$$\coth Z = \frac{\Delta}{1 + 0.167\left(\frac{a'}{c}\right)^2\left(\frac{1}{\Delta^2}\right)} = \frac{5.682}{1 + 0.167\left(\frac{1814.265}{1915}\right)^2\left(\frac{1}{32.286}\right)} = 5.6558$$

$$Z = 0.178\,75$$

$$f(Z) = 0.005\,336$$

$$S\text{-}c = \frac{a^2}{c}\,f(Z) + \frac{a^2 b^2}{72c^3}\,Z^4 = \frac{(1790)^2}{1915}\,(0.005\,336) + \frac{(1790)^2\;(680)^2}{72(1915)^3}\,(0.178\,75)^4$$

$$= 8.9280 + 0.002\,99 = 8.9310$$

$$S_0 = (S\text{-}c) + c = 8.9310 + 1915 = 1923.93$$

For "No-Load Table"

$a = 1790$

$b = 680$

$c = 1915$

$w = 2.511$

$0.5\,w = 1.2555$

$0.5\,wb = 853.74$

$a^2/c = 1673.16$

$a^2 b^2/72c^3 = 2.93$

$c/4 = 478.75$

$\dfrac{3a^2 - 2b^2}{144c} = 31.50$

$b^2/3c^2 = 0.04203$

Z	0.16	0.17	0.1788	0.18	0.19	0.20	0.21
$S\text{-}c$	7.15	8.10	8.93	9.05	10.09	11.18	12.33
S_0	1 922.15	1 923.10	1 923.93	1 924.05	1 925.09	1 926.18	1 927.33
$0.5\,wS_0$	2 413.26	2 414.45	2 415.49	2 415.64	2 416.95	2 418.32	2 419.76
T_1	16 135	15 193	14 511	14 419	13 727	13 106	12 545
T_e	15 099	14 220	14 093	13 439	12 740	12 112	11 544
d	76.73	81.54	85.781	86.36	91.18	96.00	100.83

$$AE/S_0 = 7100$$

For "Full-Load Table"

$a' = 1814.26$

$b' = 612.92$

$c = 1915$

$w' = 3.480$

$0.5\,w' = 1.740$

$0.5\,w'b' = 1066.48$

$(a')^2/c = 1718.82$

$(a')^2(b')^2/72c^3 = 2.45$

$c/4 = 478.75$

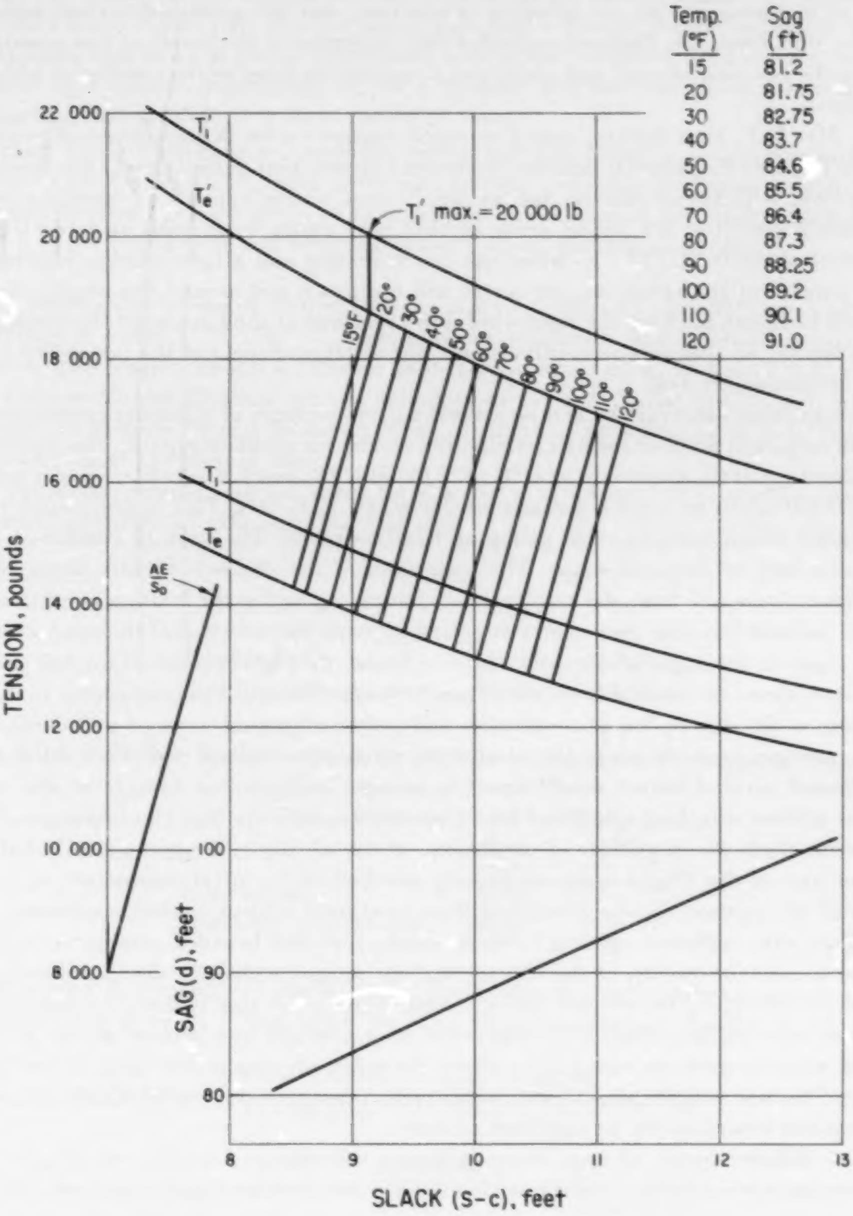
$\dfrac{3(a')^2 - 2(b')^2}{144c} = 33.08$

$(b')^3/3c^2 = 0.034\,15$

Z	0.16	0.17	0.1788	0.18	0.19	0.20	0.21
$S\text{-}c$	7.34	8.29	9.17	9.30	10.36	11.48	12.66
S_0	1 922.34	1 923.29	1 924.17	1 924.30	1 925.36	1 926.48	1 927.66
$0.5\,w'S_0$	3 344.87	3 346.52	3 348.06	3 348.28	3 350.13	3 352.08	3 354:13
T_1'	22 150	20 941	20 003	19 868	18 910	18 050	17 273
T_e'	20 924	19 705	18 758	18 622	17 654	16 783	15 996

$$\Delta S = S\alpha(10) = 1924.17(0.000\,011\,5)\,(10) = 0.2213$$

Results of these calculations are shown on figure 21 along with initial sags for temperatures from 15 to 120 °F.



Temp. (°F)	Sag (ft)
15	81.2
20	81.75
30	82.75
40	83.7
50	84.6
60	85.5
70	86.4
80	87.3
90	88.25
100	89.2
110	90.1
120	91.0

Figure 21.–Results of example problem on an inclined span using parameter *Z* method (U.S. customary). 104-D-1057.

15. Galloping Conductors.–A galloping conductor is a phenomenon usually caused by a relatively light wind of about 48 to 56 km/h (30 to 35 mi/h) blowing on an iced conductor. The ice may be in the form of either rime or glaze. A few cases of galloping conductors without the presence of ice have been noted, but these cases are extremely rare.

In 1930, Mr. A. E. Davison of the Hydroelectric Power Commission of Ontario, Canada presented the results of his pioneer work on galloping conductors, and has published several articles on the subject since that time. Mr. Davison suggested that galloping is the result of the aerodynamic lift produced by the reaction of wind and glaze, and a periodic twisting of the conductor which controls the lifting force.

In 1932, Mr. J. P. Den Hartog, noted research engineer with Westinghouse Electric Co. and instructor at Harvard Engineering School, presented a theory that galloping was the result of a glaze formation which, with the conductor, has an airfoil cross section capable of causing a certain type of aerodynamic stability. An airfoil cross section may easily be formed at a freezing-thawing temperature of about 0 °C (32 °F) when the sun is shining and a light wind is blowing. The sun will melt a portion of the radial ice, the water will run down and around the conductor, and then the water will be blown back by the light wind into the shade at the bottom of the conductor where it will again freeze. As this process continues, the airfoil takes shape and the possibility of galloping conductors becomes very real.

Based on numerous observations and on several motion pictures of galloping conductors, Davison developed an empirical method for determining the conductor oscillation path. This method is based on the stabilized sag of the conductor at 0 °C (32 °F), with 13 mm (1/2 in) of ice[2] and a wind velocity of 48.3 km/h (30 mi/h) or a wind pressure of 0.096 kPa (2 lb/ft^2). This approximates the loading condition under which most cases of galloping have occurred. The path of conductor oscillation approximates a loop of elliptical shape. The major axis of the ellipse is slightly larger (the Bureau uses a 6 percent increase) than the resultant conductor sag under the loading condition described above, and is inclined from the vertical in a direction opposite the direction of the conductor sideswing by an angle equal to the angle of sideswing. In level spans, the highest point of the full ellipse is only a small distance above the normal level of the points of attachment of the conductor to the insulator string. As long as the ellipses for all conductors and overhead ground wires of a transmission line do not overlap, galloping will not cause the conductors to come in contact with each other or with the overhead ground wires. Contact would result in outages and possible damage to the conductors. Observations of lines with long spans and heavy conductors indicate that the conductors may dance in two loops in which the magnitude of oscillation, or size of ellipse, is approximately half size; that is, the major axis of the ellipse is approximately one-half of the total conductor sag in the span. Application of this method to several existing lines, in regions subject to sleet conditions, has shown that those lines with sufficient spacing between conductors and between conductors and overhead ground wires to prevent overlap of the ellipses, had no outages under the sleet conditions. The lines that showed an overlap of the ellipses had a record of many outages under sleet conditions. There have also been observations where iced conductors have galloped in a manner similar to a skip rope being turned, with the midpoint rising as far above the points of support as it hangs below those points when at rest. This sort of galloping is rare, fortunately, because clearance limits are indicated which a designer cannot economically be expected to meet.

There is no definite length of span where galloping will change from full-sag ellipses to half-sag ellipses. However, our experience indicates that for our line locations and conditions, we should use full-sag ellipses in spans up to 183 m (600 ft) in length. In longer spans, the conductors are likely to gallop in two or more loops, so one-half size ellipses, with the major axis equal to 53 percent of the sag, should be used. If these ellipses do not overlap, the probability of contact between conductors and overhead ground wires, as a result of galloping, is greatly reduced.

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[2] For NESC heavy loading area.

Experience has shown that it is good practice to examine all hardware and very carefully check the ends of the clamps in any part of a line where galloping is known to have occurred. If galloping has created a weak spot in a conductor or excessive wear in the hardware, wind vibrations, ordinarily slow in producing a failure, concentrate on the weakened spot and can cause failure in relatively moderate weather and possibly in a short period of time.

To determine the spacing required between conductors and between conductors and overhead ground wires to prevent contact, for a particular loading condition and span length with given conductors and overhead ground wires, or to determine the maximum permissible span for a given structure with given conductors and overhead ground wires, proceed as follows:

1. For loading conditions of 13 mm (1/2 in) of ice,[3] 0.096-kPa (2-lb/ft^2) wind pressure, and a temperature of minus 1 °C (30 °F), determine the conductor and overhead ground wire sags for the given span length. Assume a 289.5-m (950-ft) span based on a 213.4-m (700-ft) ruling span.

a. Figures 22 and 23 show the sag calculations for a 242 mm^2 (477 kcmil) ACSR 24/7 conductor, and figures 24 and 25 show the sag calculations for a 10-mm (3/8-in) high-strength steel, 7-wire overhead ground wire.

b. From the calculations on these figures, for a 213.4-m (700-ft) ruling span, and for conditions conducive to galloping, the sags are:

	Sag	
	mm	(ft)
Conductor	5255	(17.24)
Overhead ground wire	4386	(14.39)

For a 289.5-m (950-ft) span, based on the 213.4-m ruling span, the sags are:

	Sag	
	mm	(ft)
Conductor	9675	(31.75)
Overhead ground wire	8075	(26.50)

2. Determine θ, the angle of sideswing, for the conductors and overhead ground wires for the loading conditions given in 1., and using the force triangles shown on figures 22, 23, 24, and 25.

a. Conductor $\theta = \tan^{-1} \dfrac{4.4898 \text{ N/m}}{21.186 \text{ N/m}}$ or $\left(\dfrac{0.3077 \text{ lb/ft}}{1.4517 \text{ lb/ft}}\right) = 11^\circ 58'$

b. Overhead ground wire $\theta = \tan^{-1} \dfrac{3.3079 \text{ N/m}}{11.777 \text{ N/m}}$ or $\left(\dfrac{0.227 \text{ lb/ft}}{0.807 \text{ lb/ft}}\right) = 15^\circ 42'$

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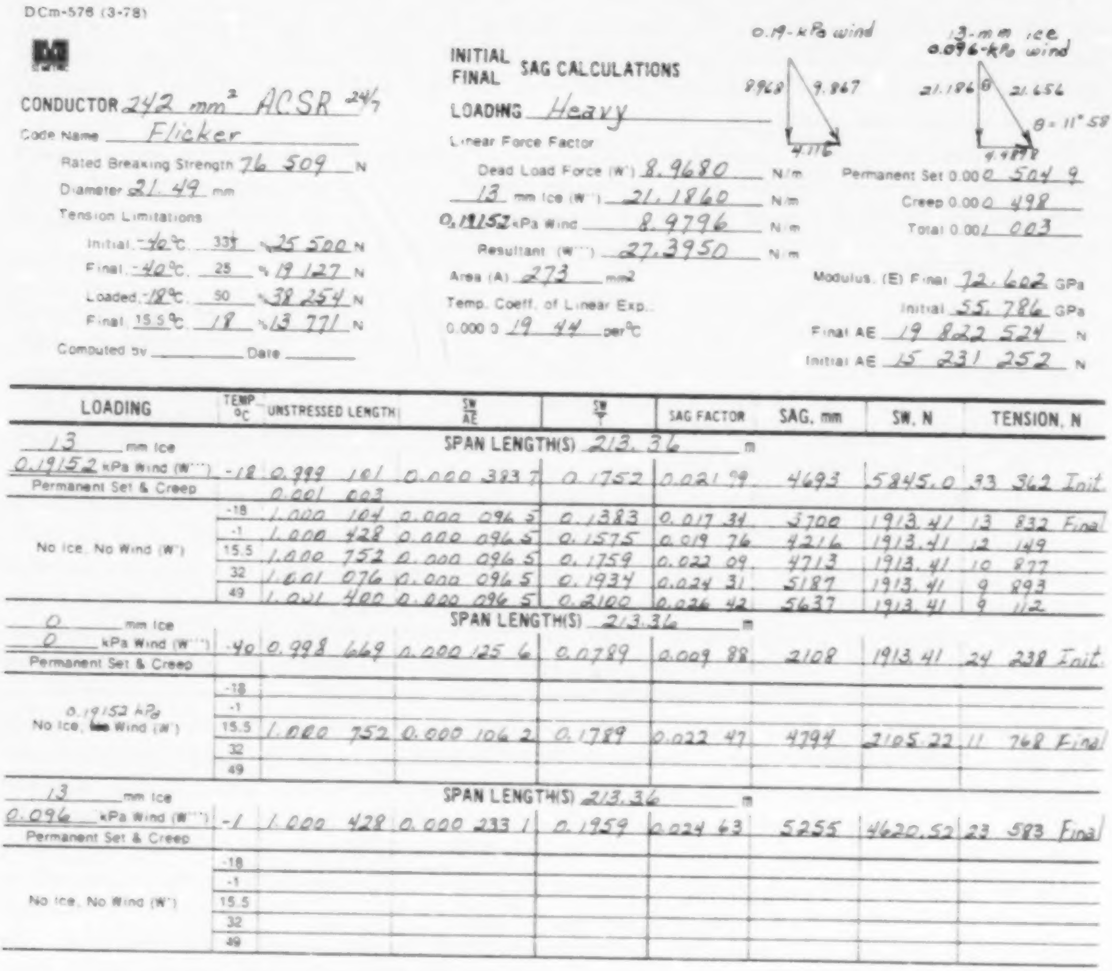
[3] For NESC heavy loading area.



DCm-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

0.19-kPa wind
9.968 9.867
4.116

13-mm ice
0.096-kPa wind
21.186 θ 21.656
θ = 11° 58'
4.4898

CONDUCTOR 242 mm² ACSR 24/7
Code Name Flicker
Rated Breaking Strength 76 509 N
Diameter 21.49 mm
Tension Limitations
Initial, -40°C, 33⅓ % 25 500 N
Final, -40°C, 25 % 19 127 N
Loaded, -18°C, 50 % 38 254 N
Final, 15.5°C, 18 % 13 771 N
Computed by ________ Date ________

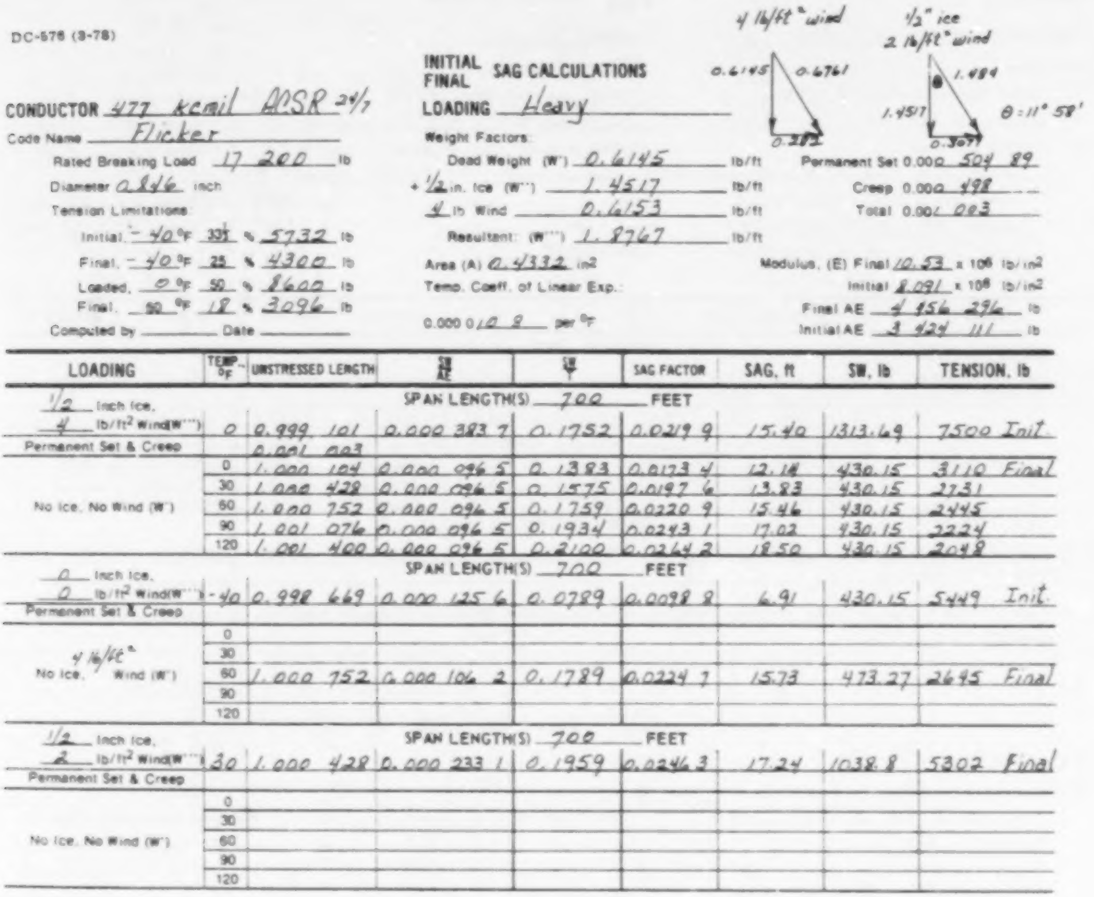
LOADING Heavy
Linear Force Factor
Dead Load Force (W') 8.9680 N/m
13 mm Ice (W'') 21.1860 N/m
0.19152 kPa Wind 8.9796 N/m
Resultant (W''') 27.3950 N/m
Area (A) 273 mm2
Temp. Coeff. of Linear Exp.,
0.000 0 19 44 per°C

Permanent Set 0.000 504 9
Creep 0.000 498
Total 0.001 003

Modulus, (E) Final 72.602 GPa
Initial 55.786 GPa
Final AE 19 822 524 N
Initial AE 15 231 252 N

LOADING	TEMP °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.19152 kPa Wind (W''')	-18	0.999 101	0.000 383 7	0.1752	0.021 99	4693	5845.0	33 362 Init.
Permanent Set & Creep		0.001 003						
No Ice, No Wind (W')	-18	1.000 104	0.000 096 5	0.1383	0.017 34	3700	1913.41	13 832 Final
	-1	1.000 428	0.000 096 5	0.1575	0.019 76	4216	1913.41	12 149
	15.5	1.000 752	0.000 096 5	0.1759	0.022 09	4713	1913.41	10 877
	32	1.001 076	0.000 096 5	0.1934	0.024 31	5187	1913.41	9 893
	49	1.001 400	0.000 096 5	0.2100	0.026 42	5637	1913.41	9 112
0 mm Ice			SPAN LENGTH(S) 213.36 m					
0 kPa Wind (W''')	-40	0.998 669	0.000 125 6	0.0789	0.009 88	2108	1913.41	24 238 Init.
Permanent Set & Creep								
0.19152 kPa No Ice, Wind (W')	-18							
	-1							
	15.5	1.000 752	0.000 106 2	0.1789	0.022 47	4794	2105.22	11 768 Final
	32							
	49							
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.096 kPa Wind (W''')	-1	1.000 428	0.000 233 1	0.1959	0.024 63	5255	4620.52	23 583 Final
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							

Figure 22.–Conductor sag and tension calculation form for example problem on galloping conductors (metric).



DC-576 (8-78)

4 lb/ft² wind
0.6145 0.6761
0.282

1/2" ice
2 lb/ft² wind
1.4517 1.484
0.3077
θ = 11° 58'

INITIAL
FINAL SAG CALCULATIONS

CONDUCTOR 477 kcmil ACSR 24/7
Code Name Flicker
Rated Breaking Load 17 200 lb
Diameter 0.846 inch
Tension Limitations:
Initial, -40 °F 33⅓ % 5732 lb
Final, -40 °F 25 % 4300 lb
Loaded, 0 °F 50 % 8600 lb
Final, 60 °F 18 % 3096 lb
Computed by ______ Date ______

LOADING Heavy
Weight Factors:
Dead Weight (W') 0.6145 lb/ft
+ 1/2 in. Ice (W'') 1.4517 lb/ft
4 lb Wind 0.6153 lb/ft
Resultant: (W''') 1.8767 lb/ft
Area (A) 0.4332 in²
Temp. Coeff. of Linear Exp.:
0.000 010 9 per °F

Permanent Set 0.000 504 89
Creep 0.000 498
Total 0.001 003
Modulus, (E) Final 10.53 × 10⁶ lb/in²
Initial 8.091 × 10⁶ lb/in²
Final AE 4 456 296 lb
Initial AE 3 424 111 lb

LOADING	TEMP °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
1/2 Inch Ice,			SPAN LENGTH(S) 700 FEET					
4 lb/ft² Wind(W''')	0	0.999 101	0.000 383 7	0.1752	0.0219 9	15.40	1313.69	7500 Init.
Permanent Set & Creep		0.001 003						
No Ice, No Wind (W')	0	1.000 104	0.000 096 5	0.1383	0.0173 4	12.14	430.15	3110 Final
	30	1.000 428	0.000 096 5	0.1575	0.0197 6	13.83	430.15	2731
	60	1.000 752	0.000 096 5	0.1759	0.0220 9	15.46	430.15	2445
	90	1.001 076	0.000 096 5	0.1934	0.0243 1	17.02	430.15	2224
	120	1.001 400	0.000 096 5	0.2100	0.0264 2	18.50	430.15	2048
0 Inch Ice,			SPAN LENGTH(S) 700 FEET					
0 lb/ft² Wind(W''')	-40	0.998 669	0.000 125 6	0.0789	0.0098 8	6.91	430.15	5449 Init.
Permanent Set & Creep								
No Ice, 4 lb/ft² Wind (W')	0							
	30							
	60	1.000 752	0.000 106 2	0.1789	0.0224 7	15.73	473.27	2645 Final
	90							
	120							
1/2 Inch Ice,			SPAN LENGTH(S) 700 FEET					
2 lb/ft² Wind(W''')	30	1.000 428	0.000 233 1	0.1959	0.0246 3	17.24	1038.8	5302 Final
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120							

Figure 23.–Conductor sag and tension calculation form for example problem on galloping conductors (U.S. customary).

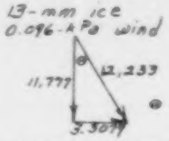
3. Construct half-sag ellipses as shown on figure 26. The major axis of the ellipse is inclined at an angle of 2θ from the plane of the conductor when the 0.096-kPa (2-lb/ft²) wind is blowing. The major axis of the ellipse is equal to one-half the sag plus 6 percent, and the minor axis is equal to one-half of the major axis. The easiest way to construct the ellipses is by the use of the trammel method, which is explained in numerous drafting or related texts.

DCm-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR 10-mm HS Steel, 7-wire
Code Name ______
Rated Breaking Strength 48 040 N
Diameter 9.144 mm
Tension Limitations
Initial, -40°C, 33⅓ % 16 013 N
Final, -40°C, 25 % 12 010 N
Loaded, -18°C, 50 % 24 020 N
Final, 15.5°C, 18 % 8 647 N
Computed by ______ Date ______

LOADING Heavy
Linear Force Factor:
Dead Load Force (W') .3984 N/m
13 mm Ice (W'') 11.777 N/m
0.19152 kPa Wind 6.616 N/m
Resultant (W''') 17.8865 N/m
Area (A) 51 mm²
Temp. Coeff. of Linear Exp.
0.000 011 88 per °C



Permanent Set 0.000 479
Creep 0.000 000
Total 0.000 479
Modulus, (E) Final 177.885 GPa
Initial 158.579 GPa
Final AE 9 089 924 N
Initial AE 8 103 387 N

LOADING	TEMP °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.19152 kPa Wind (W''')	-18	0.998 696	0.000 471 3	0.1783	0.022 39	4777	3816.26	21 418 Init.
Permanent Set & Creep		0.000 479						
No Ice, No Wind (W')	-18	0.999 175	0.000 093 5	0.0837	0.010 47	2234	850.05	10 159 Final
	-1	0.999 373	0.000 093 5	0.0939	0.011 76	2508	850.05	9 051
	15.5	0.999 571	0.000 093 5	0.1050	0.013 15	2806	850.05	8 094
	32	0.999 769	0.000 093 5	0.1167	0.014 62	3120	850.05	7 283
	49	0.999 967	0.000 093 5	0.1287	0.016 13	3441	850.05	6 605
13 mm Ice			SPAN LENGTH(S) 213.36 m					
0.09576 kPa Wind (W''')	-1	0.999 373	0.000 287 5	0.1638	0.020 56	4386	2610.03	15 951 Final
Permanent Set & Creep								

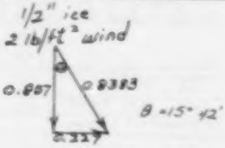
Figure 24.–Overhead ground wire sag and tension calculation form for example problem on galloping conductors (metric).

DC-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR 3/8" HS Steel, 7-wire
Code Name ______
Rated Breaking Load 10 800 lb
Diameter 0.360 inch
Tension Limitations
Initial, -40 °F 33⅓ % 3600 lb
Final, -40 °F 25 % 2700 lb
Loaded, 0 °F 50 % 5400 lb
Final, 60 °F 18 % 1944 lb
Computed by ______ Date ______

LOADING Heavy
Weight Factors:
Dead Weight (W') 0.273 lb/ft
+ 1/2 in. Ice (W'') 0.807 lb/ft
4 lb Wind 0.453 lb/ft
Resultant (W''') 1.226 lb/ft
Area (A) 0.079 17 in²
Temp. Coeff. of Linear Exp.
0.000 006 6 per °F



Permanent Set 0.000 479
Creep 0.000 000
Total 0.000 479
Modulus, (E) Final 25.8 x 10⁶ lb/in²
Initial 23.0 x 10⁶ lb/in²
Final AE 2 042 586 lb
Initial AE 1 820 910 lb

LOADING	TEMP °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
1/2 Inch Ice			SPAN LENGTH(S) 700 FEET					
4 lb/ft² Wind(W''')	0	0.998 696	0.000 471 3	0.1783	0.022 39	15.67	858.2	4815 Init.
Permanent Set & Creep		0.000 479						
No Ice, No Wind (W')	0	0.999 175	0.000 093 5	0.0837	0.010 47	7.33	191.1	2284 Final
	30	0.999 373	0.000 093 5	0.0939	0.011 76	8.23	191.1	2035
	60	0.999 571	0.000 093 5	0.1050	0.013 15	9.21	191.1	1820
	90	0.999 769	0.000 093 5	0.1167	0.014 62	10.23	191.1	1637
	120	0.999 967	0.000 093 5	0.1287	0.016 13	11.29	191.1	1485
1/2 Inch Ice,			SPAN LENGTH(S) 700 FEET					
2 lb/ft² Wind(W''')	30	0.999 373	0.000 287 5	0.1638	0.020 56	14.39	586.8	3586 Final
Permanent Set & Creep								

Figure 25.–Overhead ground wire sag and tension calculation form for example problem on galloping conductors (U.S. customary).

Type HS Structure
289.5-m (950-ft) Span
Based on 213.4-m (700-ft) ruling span
3658-mm (12-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension = 33 362 N (7500 lb)
OGW full-load tension = 21 418 N (4815 lb)
Half-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	9675	(31.75)
Half sag	4835	(15.88)
+6%	290	(0.95)
Major axis	5128	(16.83)
Minor axis	2564	(8.42)

θ = 11° 58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	8075	(26.50)
Half sag	4038	(13.25)
+6%	242	(0.79)
Major axis	4250	(14.04)
Minor axis	2125	(7.02)

θ = 15° 42'

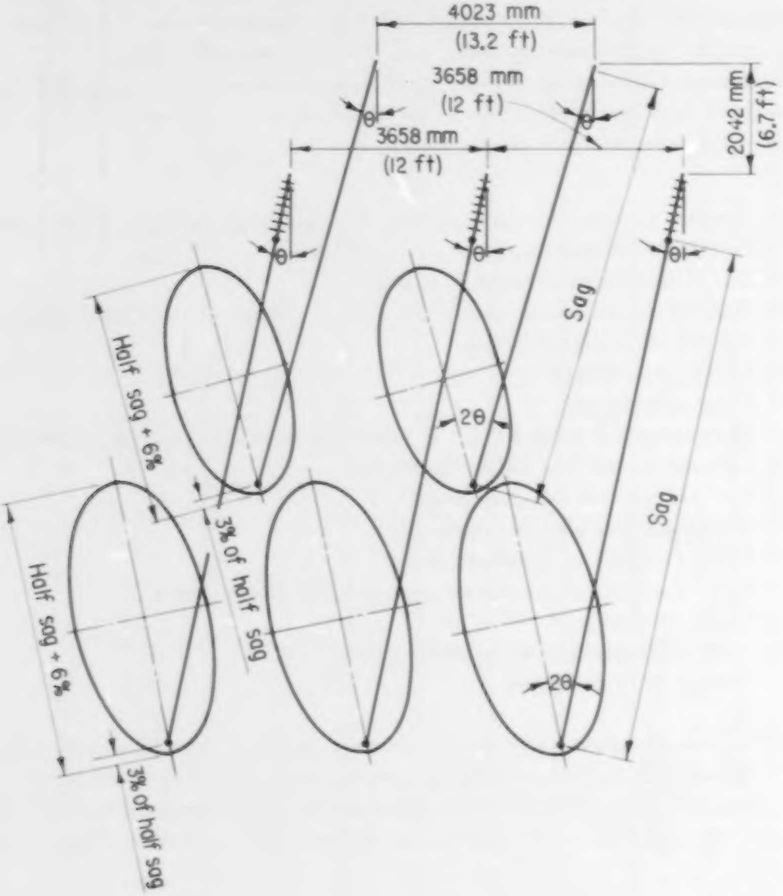

4023 mm
(13.2 ft)
3658 mm
(12 ft)
3658 mm
(12 ft)
2042 mm
(6.7 ft)
θ
θ
θ
θ
θ
Half sag + 6%
Half sag + 6%
3% of half sag
3% of half sag
2θ
2θ
Sag
Sag

Figure 26.–Half-sag ellipses for example problem on galloping conductors. 104-D-1058.

16. Broken Conductors.–The determination of sags and tensions in spans adjacent to a broken conductor is important in design work from the standpoint of assuring compliance under this condition with clearance requirements over railroad, highway, waterway, communication line, and powerline crossings; and also from the standpoint of determining the unbalanced loads on the structures. The computation of sags and tensions under this condition is somewhat complex due to the nature of the variables.

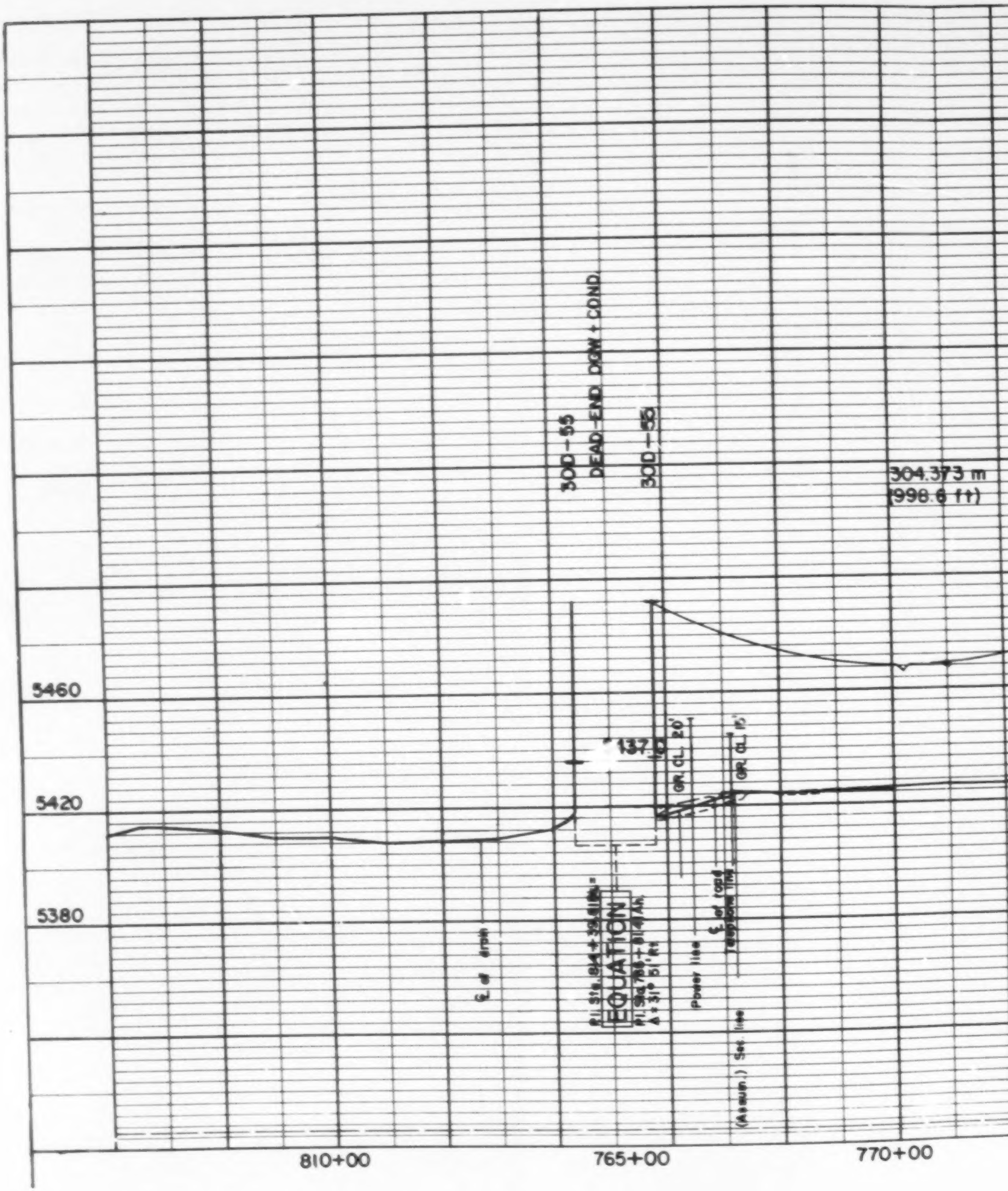
Using a technique by G. R. Wiszneauckas shown in appendix A, a broken conductor problem is given in this section for a 345-kV transmission line span over Interstate Highway No. 25 (Sta. 789+95 and 790+83) and the Colorado and Southern Railroad crossing (Sta. 795+48), both located in Colorado. Figure 27 shows the profile portion of the plan and profile drawing for this example problem. Please note that this figure is predominately in U.S. customary units; therefore, references to this figure, such as stationing, are also in those units. The conductor has been assumed as 644 mm² (1272 kcmil), ACSR, 45/7 stranding, with a full-load (NESC heavy) tension of 61 385 N (13 800 lb). Assuming a broken conductor in the span on the northwest side of the steel structure at Sta. 797+30, the ruling span for the three remaining spans to a dead-end structure is calculated to be 320.95 m (1053 ft). At 49 °C (120 °F) final conditions, the tension for this ruling span is 24 310 N (5465 lb), with a corresponding sag of 11 211 mm (36.78 ft).

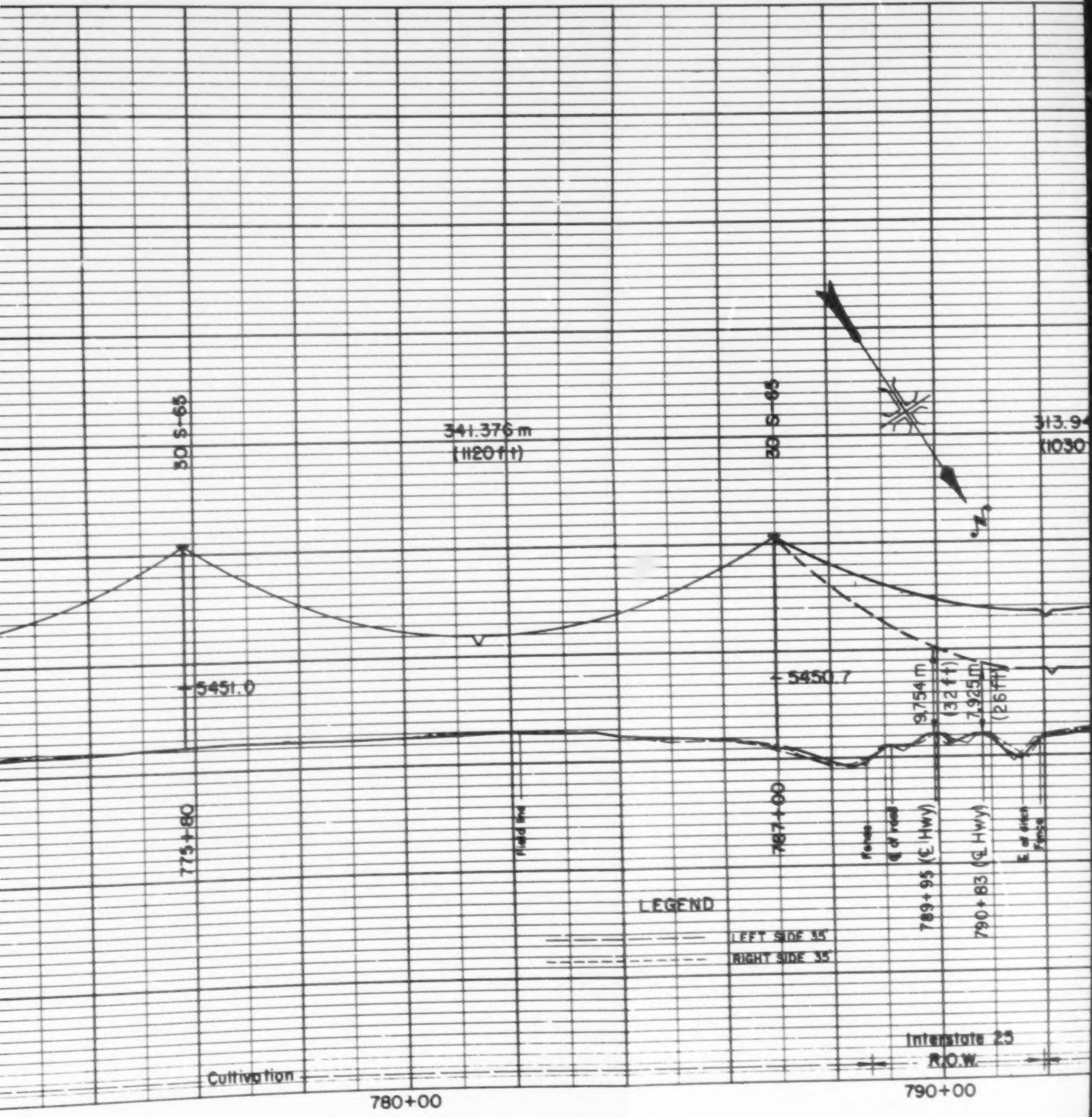
The calculations, tables, nomenclature, and broken conductor curves in this example problem are all in accordance with the broken conductor thesis shown in appendix A.

The basic nomenclature used in this section is:

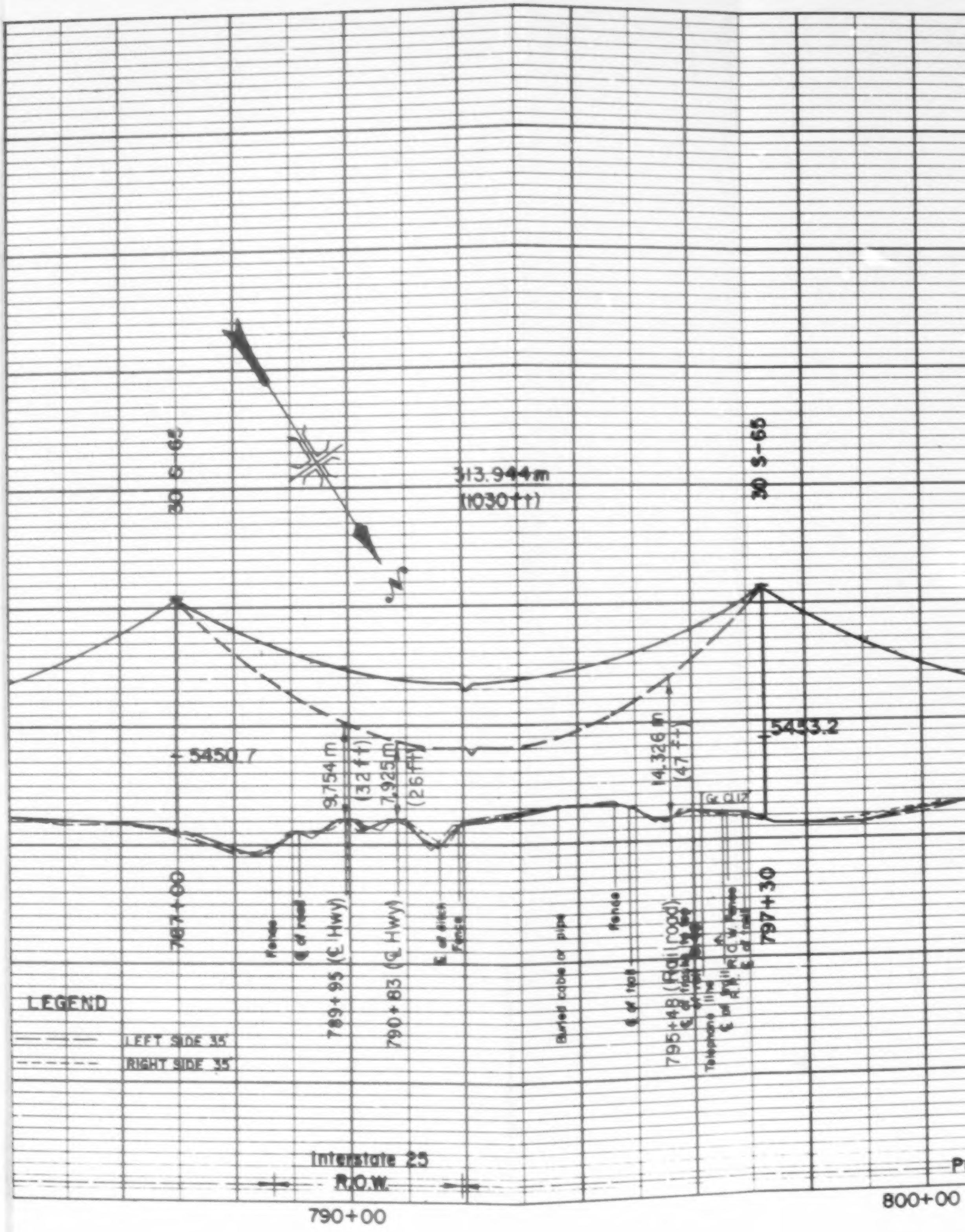
AE = Product of cross-sectional area and modulus of elasticity of the conductor
d = Horizontal displacement of insulator string
H_0 = Initial horizontal tension in conductor
H_1 = Horizontal tension in conductor after a change of ϕ in span length
i = Length of insulator string
L_0 = Initial span length
L_1 = Final span length
P = Horizontal force caused by W when the insulator string is deflected by an angle θ
s = General symbol for sag in conductor
S = General symbol for span length
w = Unit force (weight) of conductor
w_1 = Force (weight) of insulator string
w_2 = Force (weight) of conductor acting on insulator string
W = Total vertical load, $W = w_1/2 + w_2$
θ = Angle of deflection of insulator string
ϕ = Change in span length

The resulting values indicated by the curves show the suspension insulator string on the structure at Sta. 797+30 will deflect 2110 mm (83 in), and the insulator string on the structure at Sta. 787+00 will deflect about 955 mm (37.5 in). This will result in a new span length of 312.789 m (1026.21 ft) [313.944 − 2.110 + 0.955 = 312.789 m, or 1030 − 6.92 + 3.13 = 1026.21 ft]. The 24 310-N


5460
5420
5380
810+00
765+00
770+00
300-55
DEAD-END DGW + COND.
300-55
304.373 m
(998.6 ft)
137.0
GR. CL. 20'
GR. CL. 15'
℄ of drain
P.I. Sta. 814 + 32.81 Bk.
EQUATION
P.I. Sta. 765 + 81.41 Ah.
Δ = 31° 51' Rt
Power line
℄ of road
Telephone line
(Assum.) Set. line



30 S-65
341.376 m
(1120 ft)
30 S-65
313.94
(1030
N
5451.0
5450.7
9.754 m
(32 ft)
7.925 m
(26 ft)
775+80
Field line
787+00
Fence
℄ of road
789+95 (℄ Hwy)
790+83 (℄ Hwy)
E of ditch
Fence
LEGEND
LEFT SIDE 35'
RIGHT SIDE 35'
Interstate 25
R.O.W.
Cultivation
780+00
790+00


30 S-65
313.944m
(1030ft)
30 S-65
5450.7
9.754 m
(32 ft)
7.925m
(26 ft)
14.326 m
(47 ft)
5453.2
Gr. CLIZ
787+00
Fence
℄ of road
789+95 (℄ Hwy)
790+83 (℄ Hwy)
℄ of ditch
Fence
Buried cable or pipe
Fence
℄ of trail
795+48 (Railroad)
Telephone line
℄ of trail
R.O.W. Fence
797+30
LEGEND
LEFT SIDE 35'
RIGHT SIDE 35'
Interstate 25
R.O.W.
790+00
800+00
P

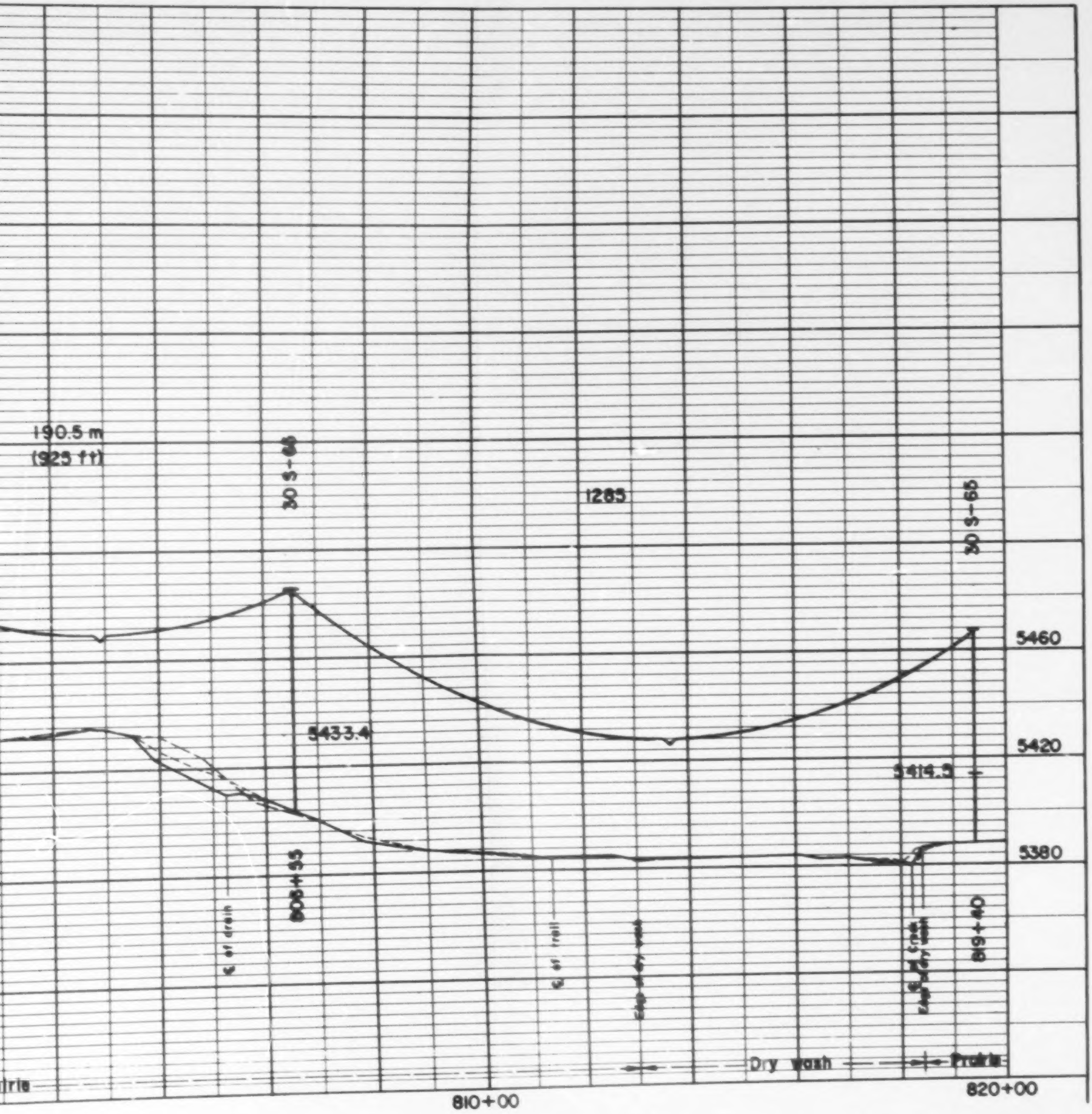

190.5 m
(625 ft)
30 S-66
1285
30 S-65
5460
5433.4
5420
5414.5
5380
℄ of drain
808+95
℄ of trail
Edge of dry wash
℄ of Creek
Edge of dry wash
819+40
Dry wash
Prairie
irie
810+00
820+00

Figure 27.–Profile of spans used for broken conductor problem. 104-D-1059. From Dwg. 864-732-1014.

(5465-lb) tension (from figs. 28 and 29) is used to compute the corresponding sag in this span with the conductor broken in the adjacent span. The calculated sag is 15 736 mm (51.64 ft) which is expanded to make the sag curve for plotting on the plan-profile. The sag in the crossing span has been shown as a dashed curve on figure 27 to indicate the expected result of a conductor break in the adjacent span.

Example 1.–Broken Conductor Calculations

Highway centerline (Sta. 789+95 and 790+83)
Railroad centerline (Sta. 795+48)
Ruling Span Calculations:

$$\text{Ruling span} = \sqrt{\frac{\Sigma\, S_1{}^3 + S_2{}^3 + S_3{}^3 + \cdots S_n{}^3}{\Sigma\, S_1 + S_2 + S_3 + \cdots S_n}}$$

where S = span length.

Metric

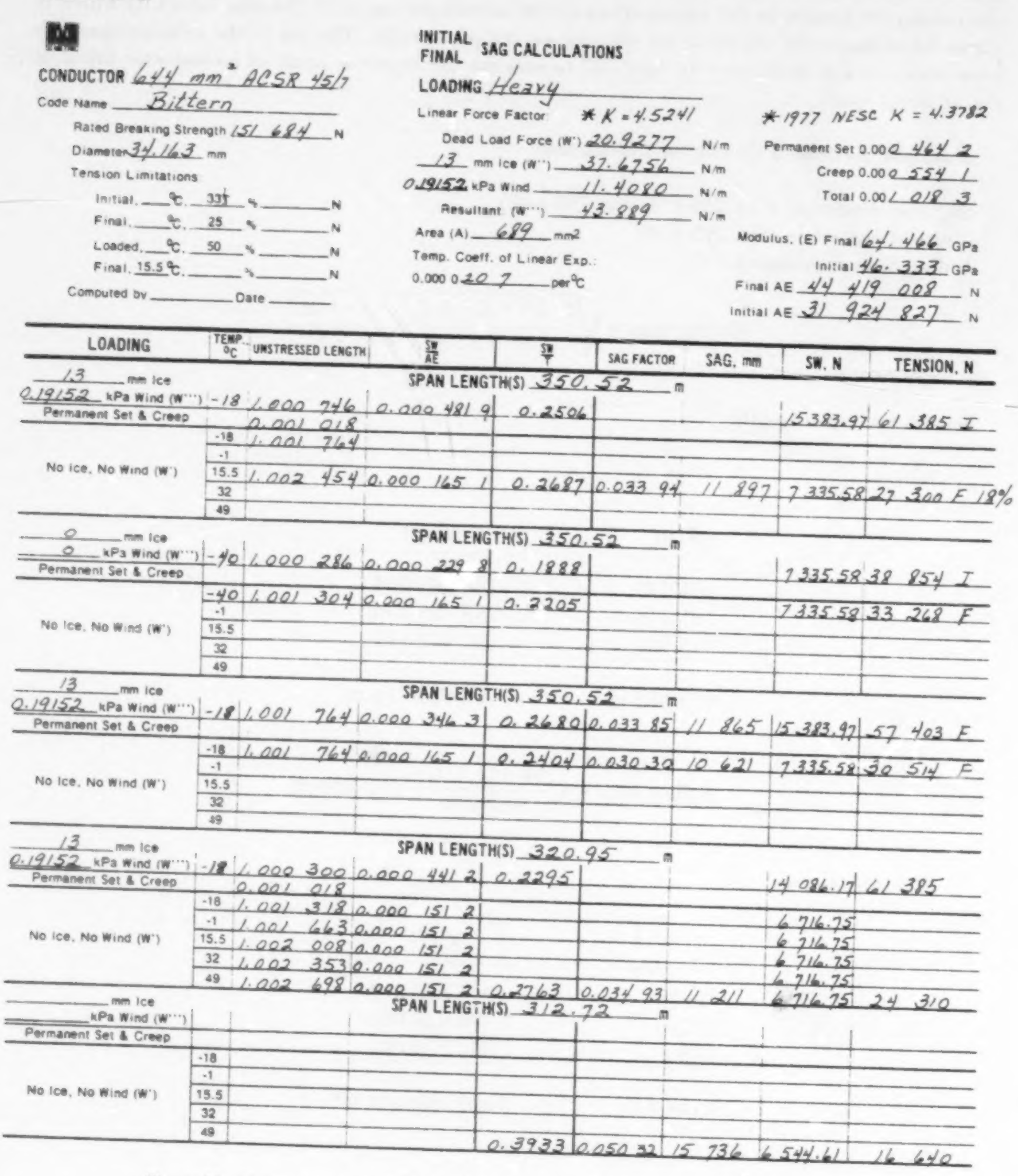
S, m	S^3, m^3
304.373	28 198 004
341.376	39 783 130
313.944	30 942 582
959.693 m	98 923 716 m^3

$$\text{Ruling span} = \sqrt{\frac{98\,923\,716}{959.693}} = 321.\,058\text{ m}$$

U.S. Customary

S, ft	S^3, ft^3
998.6	995 805 877
1120	1 404 928 000
1030	1 092 727 000
3148.6 ft	3 493 460 877 ft^3

$$\text{Ruling span} = \sqrt{\frac{3\,493\,460\,877}{3148.6}} = 1053.34\text{ ft}$$



DCm-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR 644 mm² ACSR 45/7
Code Name Bittern
Rated Breaking Strength 151 684 N
Diameter 34.163 mm
Tension Limitations
Initial, ___ °C, 33⅓ % ___ N
Final, ___ °C, 25 % ___ N
Loaded, ___ °C, 50 % ___ N
Final, 15.5 °C, ___ % ___ N
Computed by ___ Date ___

LOADING Heavy
Linear Force Factor ✱K = 4.5241
Dead Load Force (W') 20.9277 N/m
13 mm Ice (W'') 37.6756 N/m
0.19152 kPa Wind 11.4080 N/m
Resultant (W''') 43.889 N/m
Area (A) 689 mm2
Temp. Coeff. of Linear Exp.:
0.000 020 7 per °C

✱1977 NESC K = 4.3782
Permanent Set 0.000 464 2
Creep 0.000 554 1
Total 0.001 018 3
Modulus, (E) Final 64.466 GPa
Initial 46.333 GPa
Final AE 44 419 008 N
Initial AE 31 924 827 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
13 mm Ice			SPAN LENGTH(S) 350.52 m					
0.19152 kPa Wind (W''')	-18	1.000 746	0.000 481 9	0.2506			15383.97	61 385 I
Permanent Set & Creep		0.001 018						
No Ice, No Wind (W')	-18	1.001 764						
	-1							
	15.5	1.002 454	0.000 165 1	0.2687	0.033 94	11 897	7 335.58	27 300 F 18%
	32							
	49							
0 mm Ice			SPAN LENGTH(S) 350.52 m					
0 kPa Wind (W''')	-40	1.000 286	0.000 229 8	0.1888			7 335.58	38 854 I
Permanent Set & Creep								
No Ice, No Wind (W')	-40	1.001 304	0.000 165 1	0.2205			7 335.58	33 268 F
	-1							
	15.5							
	32							
	49							
13 mm Ice			SPAN LENGTH(S) 350.52 m					
0.19152 kPa Wind (W''')	-18	1.001 764	0.000 346 3	0.2680	0.033 85	11 865	15 383.97	57 403 F
Permanent Set & Creep								
No Ice, No Wind (W')	-18	1.001 764	0.000 165 1	0.2404	0.030 30	10 621	7 335.58	30 514 F
	-1							
	15.5							
	32							
	49							
13 mm Ice			SPAN LENGTH(S) 320.95 m					
0.19152 kPa Wind (W''')	-18	1.000 300	0.000 441 2	0.2295			14 086.17	61 385
Permanent Set & Creep		0.001 018						
No Ice, No Wind (W')	-18	1.001 318	0.000 151 2				6 716.75	
	-1	1.001 663	0.000 151 2				6 716.75	
	15.5	1.002 008	0.000 151 2				6 716.75	
	32	1.002 353	0.000 151 2				6 716.75	
	49	1.002 698	0.000 151 2	0.2763	0.034 93	11 211	6 716.75	24 310
___ mm Ice			SPAN LENGTH(S) 312.72 m					
___ kPa Wind (W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							
				0.3933	0.050 32	15 736	6 544.61	16 640

Figure 28.–Sag and tension calculation form for broken conductor problem (metric).

DC-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR 1272 kcmil ACSR 45/7
Code Name Bittern
Rated Breaking Load 34 100 lb
Diameter 1.345 inch
Tension Limitations:
Initial, ____ °F 33⅓ % ________ lb
Final, ____ °F 25 % ________ lb
Loaded, ____ °F 50 % ________ lb
Final, 60 °F ____ % ________ lb
Computed by ________ Date ________

LOADING Heavy
Weight Factors: * K = 0.31
Dead Weight (W') 1.4340 lb/ft
+1/2 in. Ice (W'') 2.5816 lb/ft
4 lb Wind 0.7817 lb/ft
Resultant: (W''') 3.0073 lb/ft
Area (A) 1.068 in2
Temp. Coeff. of Linear Exp.:
0.000 011 5 per °F

* 1977 NESC K = 0.30
Permanent Set 0.000 464 2
Creep 0.000 554 1
Total 0.001 018 3
Modulus, (E) Final 9.35 $\times 10^6$ lb/in^2
Initial 6.72 $\times 10^6$ lb/in^2
Final AE 9 985 800 lb
Initial AE 7 176 960 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
			SPAN LENGTH(S) 1150 FEET					
1/2 Inch Ice, 4 lb/ft^2 Wind(W''')	0	1.000 746	0.000 481 9	0.2506			3458.4	13 800 I
Permanent Set & Creep		0.001 018						
No Ice, No Wind (W')	0	1.001 764						
	30							
	60	1.002 454	0.000 165 1	0.2687	0.033 94	39.03	1649.1	6 138 F 18%
	90							
	120							
			SPAN LENGTH(S) 1150 FEET					
0 Inch Ice, 0 lb/ft^2 Wind(W''')	-40	1.000 286	0.000 229 8	0.1888			1649.1	8 735 I
Permanent Set & Creep								
No Ice, No Wind (W')	-40	1.001 304	0.000 165 1	0.2205			1649.1	7479 F
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) 1150 FEET					
1/2 Inch Ice, 4 lb/ft^2 Wind(W''')	0	1.001 764	0.000 346 3	0.2680	0.033 85	38.93	3458.4	12 904 F
Permanent Set & Creep								
No Ice, No Wind (W')	0	1.001 764	0.000 165 1	0.2404	0.030 30	34.85	1649.1	6 860 F
	30							
	60							
	90							
	120							
			SPAN LENGTH(S) 1053 FEET					
1/2 Inch Ice, 4 lb/ft^2 Wind(W''')	0	1.000 300	0.000 441 2	0.2295			3166.69	13 800
Permanent Set & Creep		0.001 018						
No Ice, No Wind (W')	0	1.001 318	0.000 151 2				1510	
	30	1.001 663	0.000 151 2				1510	
	60	1.002 008	0.000 151 2				1510	
	90	1.002 353	0.000 151 2				1510	
	120	1.002 698	0.000 151 2	0.2763	0.034 93	36.78	1510	5 465
			SPAN LENGTH(S) 1026 FEET					
____ Inch Ice, ____ lb/ft^2 Wind(W''')								
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120			0.3934	0.050 33	51.64	1471.28	3 740
			SPAN LENGTH(S) ________ FEET					
____ Inch Ice, ____ lb/ft^2 Wind(W''')								
Permanent Set & Creep								

Figure 29.–Sag and tension calculation form for broken conductor problem (U.S. customary).

Horizontal Tension Calculations:

Calculate the 49 °C (120 °F) sag and tension on sag calculation forms (figs. 28 and 29).

Then $H_0 = T - sw$, where H_0 is the horizontal tension, T is the full line tension, s is the sag, and w is the linear force factor.

Metric	U.S. Customary
$H_0 = 24\,310 - (11.211)(20.9277)$ $= 24\,075$ N	$H_0 = 5465 - (36.78)(1.434)$ $= 5412$ lb

***H* and *P* Curves:**

Tabulate the data for the H and P curves (tables 4, 5, 6, and 7). The H force is the horizontal component of tension acting in the conductor. The P force is

$$P = \frac{\text{[4]}\,W_T d}{i \cos \theta}$$

and is the horizontal force which resists the movement of an insulator string of length i from the vertical to any angle θ while a vertical load W_T is acting.

Plot the H and P curves (figs. 30 and 31) from the data in tables 4, 5, 6, and 7.

Table 4.–*P curve computations for example problem No. 1–broken conductor (metric)*

$$P = \frac{W_T d}{i \cos \theta}$$

[1] $W_T = 7095$ N $i = 2286$ mm

d, mm	$d/i = \sin \theta$	$\cos \theta$	$\frac{d/i}{\cos \theta}$	P, N
500	0.2187	0.9758	0.2241	1 589.99
1000	.4374	.8992	.4864	3 451.01
1250	.5468	.8373	.6531	4 633.74
1500	.6562	.7546	.8696	6 169.81
1650	.7218	.6921	1.0429	7 399.38
1800	.7874	.6164	1.2774	9 063.15
1950	.8530	.5219	1.6344	11 596.07
2050	.8968	.4425	2.0267	14 379.44
2150	.9405	.3398	2.7678	19 637.54

[1] W_T = vertical force at attachment point, which is one-half the insulator force plus force of conductor.

---

[4] W_T has been used in this section for clarity; it is shown as W in appendix A.

Table 5.–*P curve computations for example problem No. 1–broken conductor (U.S. customary)*

$$P = \frac{W_T d}{i \cos \theta}$$

[1] W_T = 1595 lb i = 7.5 ft = 90 in

d, in	$d/i = \sin \theta$	$\cos \theta$	$\frac{d/i}{\cos \theta}$	P, lb
20	0.2222	0.9750	0.2279	363.50
40	.4444	.8958	.4961	791.28
50	.5555	.8315	.6681	1065.62
60	.6667	.7453	.8945	1426.73
65	.7222	.6917	1.0441	1665.34
70	.7778	.6285	1.2375	1973.81
75	.8333	.5528	1.5074	2404.30
80	.8889	.4581	1.9404	3094.94
85	.9444	.3288	2.8723	4581.32

[1] W_T = vertical weight at attachment point, which is one-half the insulator weight plus weight of conductor.

Table 6.–*H curve computations for example problem No. 1–broken conductor (metric)*

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1} \right]$$

H_0 = 24 075 N L_0 = 321 m w = 20.9277 N/m AE = 44 419 008 N

1	2	3	4	5	6	7	8	9
H_1, N	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$(5)	$\frac{2H_1}{w}$	(6) (7)	$\phi = L_0 -$ (8), m
12 000	3369.803 431	0.999 728	3368.886 844	0.280 741	0.277 178	1146.8054	317.869 227	3.130 77
13 000	3369.803 431	.999 751	3368.964 350	.259 151	.256 335	1242.3725	318.463 555	2.536 45
14 000	3369.803 431	.999 773	3369.038 486	.240 646	.238 382	1337.9397	318.940 742	2.059 26
16 000	3369.803 431	.999 818	3369.190 127	.210 574	.209 048	1529.0739	319.649 841	1.350 16
18 000	3369.803 431	.999 863	3369.341 768	.187 186	.186 110	1720.2081	320.147 930	0.852 07
20 000	3369.803 431	.999 908	3369.493 409	.168 475	.167 688	1911.3424	320.509 184	.490 82
22 000	3369.803 431	.999 953	3369.645 050	.153 166	.152 573	2102.4766	320.781 162	.218 84
24 075	3369.803 431	1.000 000	3369.803 431	.139 971	.139 518	2300.7784	321.000 001	.000 00

Numbers in parenthesis are column numbers.

Table 7.–*H curve computations for example problem No. 1–broken conductor (U.S. Customary)*

$$\phi = L_0 - \frac{2H_1}{w}\sinh^{-1}\left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1}\right]$$

$H_0 = 5412$ lb $L_0 = 1053$ ft $w = 1.4340$ lb/ft $AE = 9\,985\,800$

1	2	3	4	5	6	7	8	9	10
H_1, lb	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}(5)$	$\frac{2H_1}{w}$	(6) (7)	$\phi = L_0 - (8)$, ft	$\phi = L_0 - (8)$, in
2700	757.452 311	0.999 728	757.246 284	0.280 462	0.276 910	3765.5904	1042.7573	10.24	122.88
2900	757.452 311	.999 748	757.261 433	.261 125	.258 245	4044.6304	1044.5056	8.49	101.88
3200	757.452 311	.999 778	757.284 157	.236 651	.234 496	4463.0404	1046.5651	6.43	77.16
3500	757.452 311	.999 809	757.307 638	.216 374	.214 720	4881.4505	1048.1451	4.85	58.20
4000	757.452 311	.999 859	757.345 510	.189 336	.188 223	5578.8006	1050.0586	2.94	35.28
4500	757.452 311	.999 909	757.383 383	.168 307	.167 522	6276.1506	1051.3933	1.61	19.32
5000	757.452 311	.999 959	757.421 256	.151 484	.150 911	6973.5007	1052.3780	0.62	7.44
5412	757.452 311	1.000 000	757.452 311	.139 958	.139 505	7548.1172	1053.0001	0.00	0.00

Numbers in parenthesis are column numbers.

Read the insulator deflections from completed curves on figures 30 and 31:

2110 mm (83 in) at Sta. 797+30
955 mm (37.5 in) at Sta. 787+00

Then, the new span length for the crossing span is equal to:

313.944 m (1030 ft) – 2.110 m (6.92 ft) + 0.955 m (3.13 ft) = 312.789 m (1026.21 ft).

Read the horizontal tension (figs. 30 and 31) in the conductor at the first suspension point (Sta. 797+30). Use this value of tension, 16 640 N (3740 lb), and figures 28 and 29 to compute the corresponding 49 °C (120 °F) sag. The horizontal component of tension in the conductor may now be corrected to the line tension, if desired:

$T = H + sw = 16\,640 + (15.736)(20.9277) = 16\,969$ N, or $3740 + (51.64)(1.434) = 3814$ lb.

The difference in sag due to this correction is small, and the use of the corrected horizontal tension results in a slightly larger sag than would actually exist; therefore, by ignoring the correction, actual clearances over obstructions will be slightly greater than those computed. For these reasons, the corrections in sag and tension are seldom made.

Sag curve for broken conductor:

Metric

$$K = Sag/Span^2 = \frac{15.736}{(313)^2} = 1.6062 \text{ x } 10^{-4}\,\text{m}^{-1}$$

Span, m	$(Span)^2$, $m^2 \times 10^4$	$Sag = (K)\,(Span)^2$, m
48	0.2304	0.370
96	0.9216	1.480
144	2.0736	3.331
192	3.6864	5.921
240	5.7600	9.252
288	8.2944	13.322
366	11.2896	18.133

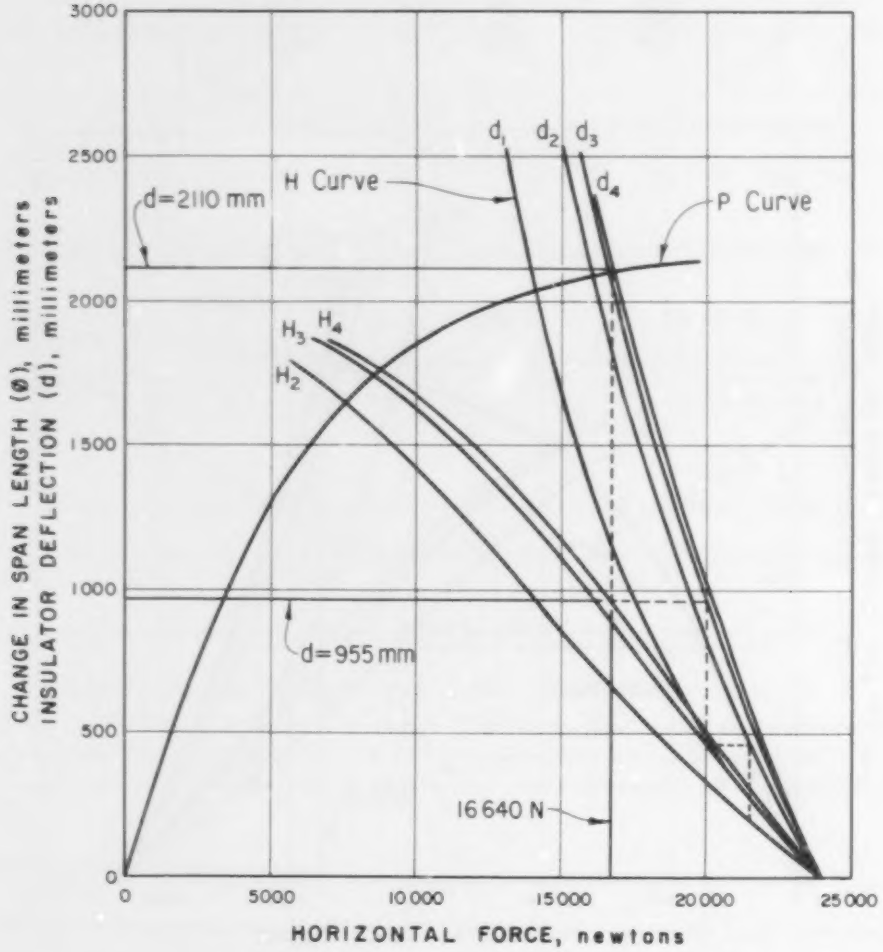


Figure 30.–Curves for broken conductor problem (metric). 104-D-1060.

U.S. Customary

$$K = Sag/Span^2 = \frac{51.64}{(1026)^2} = 4.9056 \times 10^{-5}\ \text{ft}^{-1}$$

Span, ft	*(Span)*^{2}, ft^2 x 10^5	*Sag* = *(K) (Span)*^{2}, ft
200	0.4	1.96
400	1.6	7.85
600	3.6	17.66
800	6.4	31.40
1000	10.0	49.06
1200	14.4	70.64
1400	19.6	96.15
1600	25.6	125.58
1800	32.4	158.94
2000	40.0	196.22

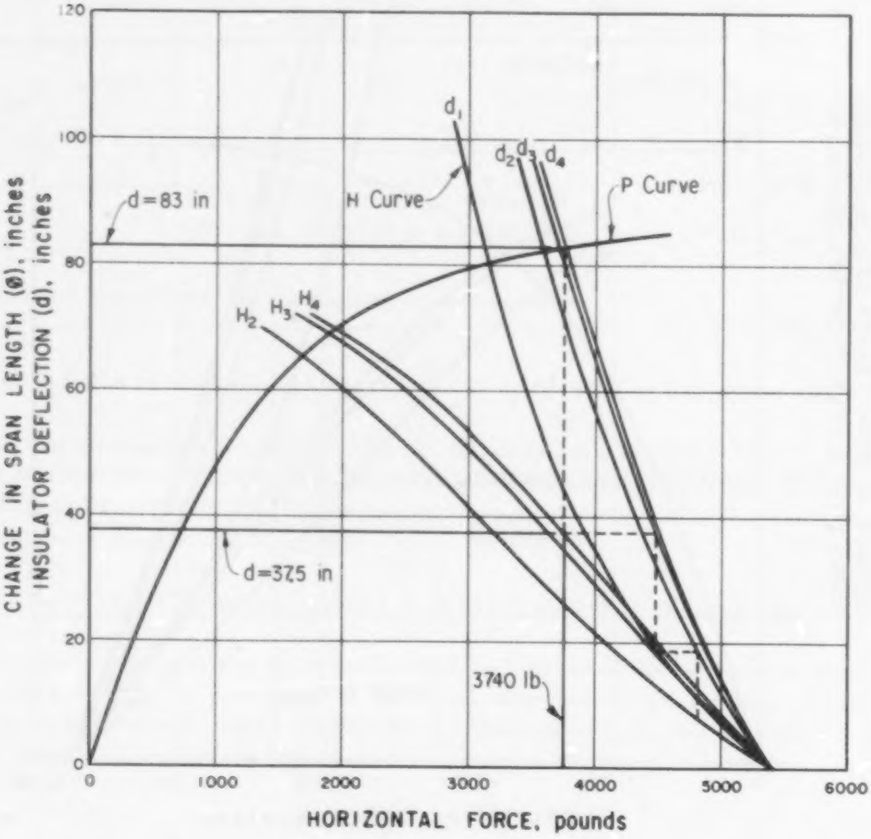


Figure 31.–Curves for broken conductor problem (U.S. customary). 104-D-1061.

The sag template for the span with reduced tension due to the broken conductor is shown on figure 32.

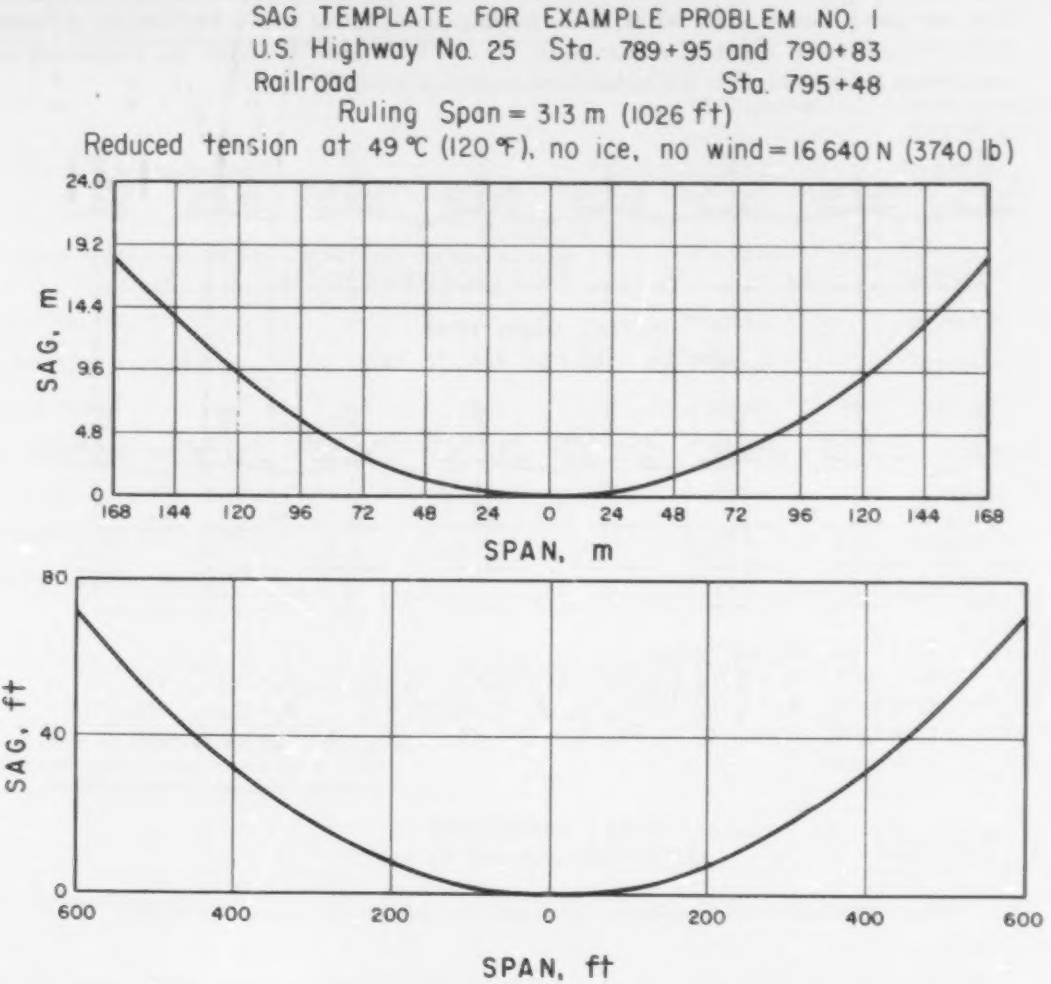


Figure 32.–Sag template for reduced tension due to broken conductor. 104-D-1062.

The broken conductor curve plotted on figure 27 indicates there would be conductor clearances to the highway of 9754 mm (32 ft) at Sta. 789+95 and 7925 mm (26 ft) at Sta. 790+83. The clearance to the railroad would be 14 326 mm (47 ft). These clearances all meet NESC and State requirements.

Example 2.–Unbalanced Condition

Any number of real or imaginary problems may be studied by use of the broken conductor thesis shown in appendix A. A hypothetical situation has been assumed to illustrate the use of a more involved solution using the basic broken conductor concept:

A transmission line with a bundle of two 644 mm^2 (1272 kcmil), ACSR, 45/7 conductors, and a series of 350.5-m (1150-ft) spans has been assumed for this study of an unbalanced load situation. All spans, except one, have no ice and no wind load at minus 18 °C (0 °F). The excepted span is loaded under NESC heavy loading conditions of 13-mm (1/2-in) ice, 0.19-kPa (4-lb/ft^2) wind, plus constant at minus 18 °C (0 °F). Figure 33 shows the conditions for equilibrium before and after the unbalanced condition exists.

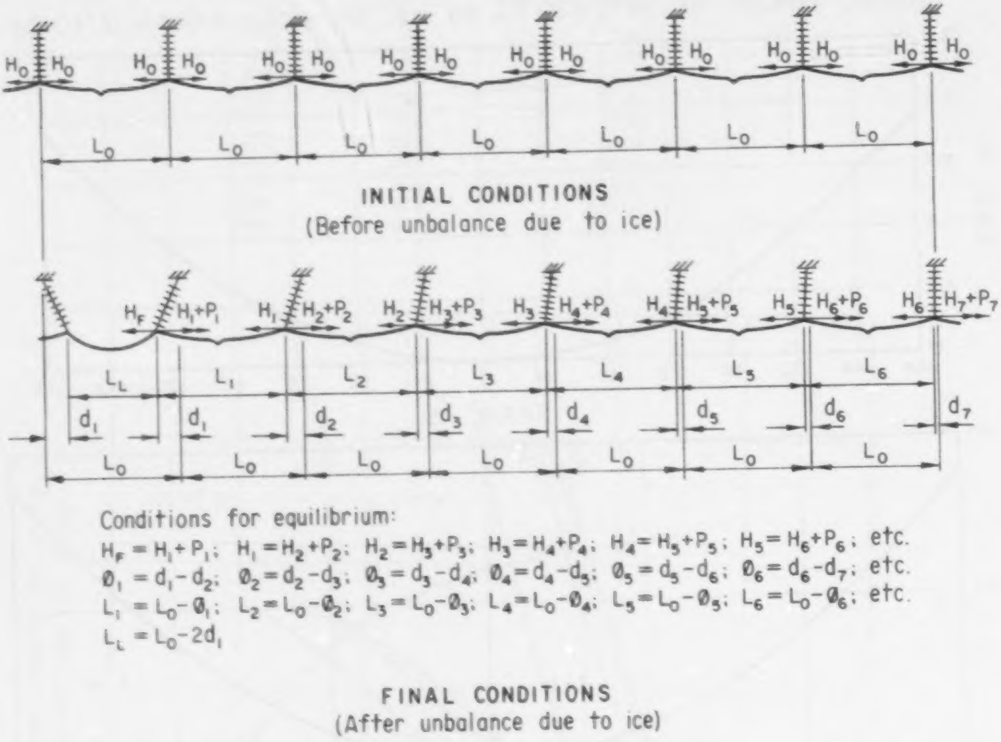

H₀ H₀
L₀
INITIAL CONDITIONS
(Before unbalance due to ice)
H_F H₁+P₁ H₁ H₂+P₂ H₂ H₃+P₃ H₃ H₄+P₄ H₄ H₅+P₅ H₅ H₆+P₆ H₆ H₇+P₇
L_L L₁ L₂ L₃ L₄ L₅ L₆
d₁ d₁ d₂ d₃ d₄ d₅ d₆ d₇
Conditions for equilibrium:
H_F = H₁+P₁; H₁ = H₂+P₂; H₂ = H₃+P₃; H₃ = H₄+P₄; H₄ = H₅+P₅; H₅ = H₆+P₆; etc.
Ø₁ = d₁−d₂; Ø₂ = d₂−d₃; Ø₃ = d₃−d₄; Ø₄ = d₄−d₅; Ø₅ = d₅−d₆; Ø₆ = d₆−d₇; etc.
L₁ = L₀−Ø₁; L₂ = L₀−Ø₂; L₃ = L₀−Ø₃; L₄ = L₀−Ø₄; L₅ = L₀−Ø₅; L₆ = L₀−Ø₆; etc.
L_L = L₀−2d₁
FINAL CONDITIONS
(After unbalance due to ice)

Figure 33.–Conditions for equilibrium before and after unbalanced condition. 104-D-1063.

Conductor data and data for plotting the *P* and *H* curves are shown in tables 8 through 1 and the graphical solution is shown on figures 34 and 35.

The procedure for the graphical solution is:

1. Lay out the graph axes using millimeters (inches) for the ordinate values of chan in span length ϕ and insulator deflection *d*. Use newtons (pounds) for the abscissa values horizontal force. Allow room on the graph for the development of curves in both the fi and fourth quadrants.
2. Plot the P_{L_1} curve by plotting *d* versus P_1 using table 10 or 11.
3. Plot the P_{L_2} curve by plotting *d* versus P_2 using table 10 or 11.
4. Plot the $P_{L_1} + {L_2}$ curve by plotting *d* versus $(P_1 + P_2)/2$ using table 10 or 11. simplify calculations, this is taken as the average *P* force in the series of spans bei computed.

Table 8.–*Line data computations for example problem No. 2–unbalanced condition (metric)*

Two 644 mm^2, ACSR, 45/7 (duplex conductors)
Maximum conductor tension = 61 385 N, initial
Twenty 177 928-N insulator units per suspension string

		-18 °C, no load	-18 °C, 13-mm ice, 0.19-kPa wind
Insulator string vertical force (w_1)		1 156.5 N	1 156.5 N
0.5 w_1		578.3N	578.3 N
Conductor vertical force, 350.5-m span (w_2)	20.9277 N/m (no load) x 2 cond.	14 670.3 N	
	43.889 N/m (full load) x 2 cond.		30 766.2 N
$W_T = 0.5\ w_1 + w_2$		15 248.6 N	31 344.5 N
Insulator string length (*i*)		3 734 mm	3 734 mm
Tension (*T*) final		30 514 N	57 403 N
Conductor vertical force (*w*)		20.927 7 N/m	43.889 N/m
Sag (*s*), 350.5-m span		10 621 mm	11 865 mm
Horizontal tension ($H_0 = T - sw$)		30 292 N	56 882 N
Area times final modulus (*AE*)		44 419 008 N	44 419 008 N

Table 9.–*Line data computations for example problem No. 2–unbalanced condition (U.S. customary)*

Two 1272 kcmil, ACSR, 45/7 (duplex conductors)
Maximum conductor tension = 13 800 lb, initial
Twenty 40 000-lb insulator units per suspension string

		0 °F, no load	0 °F, 1/2-in ice, 4-lb/ft^2 wind
Insulator string weight (w_1)		260 lb	260 lb
0.5 w_1		130 lb	130 lb
Conductor weight, 1150-ft span (w_2)	1.4340 lb/ft (no load) x 2 cond.	3 298.2 lb	
	3.0073 lb/ft (full load) x 2 cond.		6 916.8 lb
$W_T = 0.5\ w_1 + w_2$		3 428.2 lb	7 046.8 lb
Insulator string length (*i*)		147 in	147 in
Tension (*T*) final		6 860 lb	12 904 lb
Conductor weight (*w*)		1.434 lb/ft	3.007 3 lb/ft
Sag (*s*), 1150-ft span		34.85 ft	38.93 ft
Horizontal tension ($H_0 = T - sw$)		6 810 lb	12 787 lb
Area times final modulus (*AE*)		9 985 800 lb	9 985 800 lb

Table 10.–*P curve computations for example problem No. 2–unbalanced condition (metric)*

$$P = \frac{W_T d}{i \cos \theta}$$

W_T = 15 248.6 N (no load), 31 344.5 N (full load) i = 3734 mm

d, mm	$d/i = \sin \theta$	$\cos \theta$	$\frac{d/i}{\cos \theta}$	No load P_1	Full load P_2	$\frac{P_1 + P_2}{2}$
500	0.133 90	0.990 99	0.135 12	2 060.39	4 235.27	3 147.84
1000	.267 81	.963 47	.277 96	4 238.50	8 712.52	6 475.52
1500	.401 71	.915 77	.438 66	6 688.95	13 749.58	10 219.29
2000	.535 62	.844 46	.634 28	9 671.88	19 881.19	14 776.57
2500	.669 52	.742 79	.901 36	13 744.48	28 252.68	20 998.62
3000	.803 43	.595 40	1.349 40	20 576.46	42 296.27	31 436.43
3250	.870 38	.492 38	1.767 70	26 954.95	55 407.67	41 181.40
3375	.903 86	.427 83	2.112 66	32 215.11	66 220.27	49 217.79
3500	.937 33	.348 44	2.690 08	41 019.95	84 319.21	62 699.72
3600	.964 11	.265 50	3.631 30	55 372.24	113 821.28	84 596.94
3650	.977 50	.210 94	4.634 02	70 662.32	145 251.04	107 956.91
3700	.990 89	.134 67	7.357 91	112 197.83	230 630.01	171 414.29
3734	1.000 00	.000 00				

Table 11.–*P curve computations for example problem No. 2–unbalanced condition (U.S. customary)*

$$P = \frac{W_T d}{i \cos \theta}$$

W_T = 3428.2 lb (no load), 7046.8 lb (full load) i = 147 in

d, in	$d/i = \sin \theta$	$\cos \theta$	$\frac{d/i}{\cos \theta}$	No load P_1	Full load P_2	$\frac{P_1 + P_2}{2}$
20	0.136 05	0.990 70	0.137 33	470.79	967.74	719.27
40	.272 11	.962 27	.282 78	969.43	1 992.69	1 481.06
60	.408 16	.912 91	.447 10	1 532.75	3 150.62	2 341.69
80	.544 22	.838 94	.648 70	2 223.87	4 571.26	3 397.57
100	.680 27	.732 96	.928 11	3 181.75	6 540.21	4 860.98
120	.816 33	.577 59	1.413 34	4 845.21	9 959.52	7 402.37
130	.884 35	.466 82	1.894 41	6 494.42	13 349.53	9 921.97
135	.918 37	.395 72	2.320 76	7 956.03	16 353.93	12 154.98
140	.952 38	.304 91	3.123 48	10 707.91	22 010.54	16 359.23
142	.965 99	.258 58	3.735 75	12 806.90	26 325.08	19 565.99
144	.979 59	.201 01	4.873 34	16 706.78	34 341.45	25 524.12
146	.993 20	.116 42	8.531 18	29 246.59	60 117.52	44 682.06
147	1.000 00	.000 00				

Table 12.–*H curve computation for example problem No. 2–unbalanced full-load condition (metric)*

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1} \right]$$

$H_0 = 56\ 882$ N $\quad L_0 = 350.5$ m $\quad w = 43.889$ N/m $\quad AE = 44\ 419\ 008$ N

1	2	3	4	5	6	7	8	9
H_1, N	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$ (5)	$\frac{2H_1}{w}$	(6) (7)	$\phi = L_0 -$ (8), m
13 600	7 715.007 734	0.999 023	7 707.470 171	0.570 924	0.543 733	615.1883	334.50	16.00
15 750	7 715.007 734	.999 074	7 707.863 637	.489 388	.471 700	717.7197	338.55	11.95
18 000	7 715.007 734	.999 125	7 708.257 102	.428 237	.416 123	820.2511	341.33	9.17
22 500	7 715.007 734	.999 226	7 709.036 318	.342 624	.336 252	1025.3139	344.76	5.74
27 000	7 715.007 734	.999 327	7 709.815 534	.285 549	.281 804	1230.3766	346.73	3.77
31 500	7 715.007 734	.999 429	7 710.602 465	.244 781	.242 400	1435.4394	347.95	2.55
36 000	7 715.007 734	.999 530	7 711.381 680	.214 205	.212 600	1640.5022	348.77	1.73
40 500	7 715.007 734	.999 631	7 712.160 896	.190 424	.189 292	1845.5649	349.35	1.15
45 000	7 715.007 734	.999 733	7 712.947 827	.171 399	.170 571	2050.6277	349.78	0.72
50 000	7 715.007 734	.999 845	7 713.811 908	.154 276	.153 670	2278.4752	350.13	0.37
56 882	7 715.007 734	1.000 000	7 715.007 734	.135 632	.135 220	2592.0846	350.5017	0.0085
60 000	7 715.007 734	1.000 070	7 715.547 785	.128 592	.128 240	2734.1703	350.63	−0.13
65 000	7 715.007 734	1.000 183	7 716.419 580	.118 714	.118 437	2962.0178	350.81	−0.31
70 000	7 715.007 734	1.000 295	7 717.283 661	.110 247	.110 025	3189.8653	350.96	−0.46
75 000	7 715.007 734	1.000 408	7 718.155 457	.102 909	.102 728	3417.7129	351.09	−0.59
80 000	7 715.007 734	1.000 520	7 719.019 538	.096 488	.096 339	3645.5604	351.21	−0.71
85 000	7 715.007 734	1.000 633	7 719.891 334	.090 822	.090 698	3873.4079	351.31	−0.81
90 000	7 715.007 734	1.000 746	7 720.763 130	.085 786	.085 681	4101.2554	351.40	−0.90
95 000	7 715.007 734	1.000 858	7 721.627 211	.081 280	.081 191	4329.1030	351.48	−0.98
100 000	7 715.007 734	1.000 971	7 722.499 007	.077 225	.077 148	4556.9505	351.56	−1.06
105 000	7 715.007 734	1.001 083	7 723.363 087	.073 556	.073 490	4784.7980	351.63	−1.13
110 000	7 715.007 734	1.001 196	7 724.234 883	.070 220	.070 162	5012.6455	351.70	−1.20
113 764	7 715.007 734	1.001 281	7 724.890 659	.067 902	.067 850	5184.1692	351.75	−1.25
115 000	7 715.007 734	1.001 308	7 725.098 964	.067 175	.067 125	5240.4931	351.77	−1.27
120 000	7 715.007 734	1.001 421	7 725.970 760	.064 383	.064 339	5468.3406	351.83	−1.33

Numbers in parenthesis are column numbers.

Table 13.–*H curve computations for example problem No. 2–unbalanced full-load condition (U.S. customary)*

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1} \right]$$

H_0 = 12 787 lb L_0 = 1150 ft w = 3.0073 lb/ft AE = 9 985 800 lb

1	2	3	4	5	6	7	8	9	10
H_1, lb	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$ (5)	$\frac{2H_1}{w}$	(6) (7)	$\phi = L_0 -$ (8), ft	$\phi = L_0 -$ (8), in
3 000	1 734.472 747	0.999 020	1 732.772 964	0.577 591	0.549 515	1 995.145 2	1096.36	53.64	643.68
3 500	1 734.472 747	.999 070	1 732.859 687	.495 103	.476 828	2 327.669 3	1109.90	40.10	481.20
4 000	1 734.472 747	.999 120	1 732.946 411	.433 237	.420 715	2 660.193 5	1119.18	30.82	369.84
5 000	1 734.472 747	.999 220	1 733.119 858	.346 624	.340 033	3 325.241 9	1130.69	19.31	231.72
6 000	1 734.472 747	.999 320	1 733.293 306	.288 882	.285 008	3 990.290 3	1137.26	12.74	152.88
7 000	1 734.472 747	.999 420	1 733.466 753	.247 638	.245 174	4 655.338 7	1141.37	8.63	103.56
8 000	1 734.472 747	.999 521	1 733.641 935	.216 705	.215 044	5 320.387 1	1144.12	5.88	70.56
9 000	1 734.472 747	.999 621	1 733.815 382	.192 646	.191 474	5 985.435 4	1146.06	3.94	47.28
10 000	1 734.472 747	.999 721	1 733.988 829	.173 399	.172 542	6 650.483 8	1147.49	2.51	30.12
11 000	1 734.472 747	.999 821	1 734.162 276	.157 651	.157 005	7 315.532 2	1148.58	1.42	17.04
12 000	1 734.472 747	.999 921	1 734.335 724	.144 528	.144 030	7 980.580 6	1149.44	0.56	6.72
12 787	1 734.472 747	1.000 000	1 734.472 747	.135 643	.135 230	8 503.973 7	1149.9924	0.01	0.09
14 000	1 734.472 747	1.000 121	1 734.682 618	.123 906	.123 591	9 310.677 4	1150.72	-0.72	-8.64
15 000	1 734.472 747	1.000 222	1 734.857 800	.115 657	.115 401	9 975.725 7	1151.21	-1.21	-14.52
16 000	1 734.472 747	1.000 322	1 735.031 247	.108 439	.108 228	10 640.774 1	1151.63	-1.63	-19.56
17 000	1 734.472 747	1.000 422	1 735.204 694	.102 071	.101 895	11 305.822 5	1152.01	-2.01	-24.12
18 000	1 734.472 747	1.000 522	1 735.378 142	.096 410	.096 261	11 970.870 9	1152.33	-2.33	-27.96
19 000	1 734.472 747	1.000 622	1 735.551 589	.091 345	.091 218	12 635.919 3	1152.62	-2.62	-31.44
20 000	1 734.472 747	1.000 722	1 735.725 036	.086 786	.086 677	13 300.967 6	1152.89	-2.89	-34.68
21 000	1 734.472 747	1.000 822	1 735.898 480	.082 662	.082 568	13 966.016 0	1153.15	-3.15	-37.80
22 000	1 734.472 747	1.000 923	1 736.073 665	.078 912	.078 830	14 631.064 4	1153.37	-3.37	-40.44
23 000	1 734.472 747	1.001 023	1 736.247 113	.075 489	.075 417	15 296.112 8	1153.59	-3.59	-43.08
24 000	1 734.472 747	1.001 123	1 736.420 560	.072 351	.072 288	15 961.161 2	1153.80	-3.80	-45.60
25 000	1 734.472 747	1.001 223	1 736.594 007	.069 464	.069 408	16 626.209 6	1153.99	-3.99	-47.88
25 574	1 734.472 747	1.001 281	1 736.694 607	.067 909	.067 857	17 007.947 3	1154.11	-4.11	-49.32

Numbers in parenthesis are column numbers.

Table 14.–*H curve computations for example problem No. 2–unbalanced no-load condition (metric)*

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1} \right]$$

$H_0 = 30\ 292$ N $\qquad L_0 = 350.5$ m $\qquad w = 20.9277$ N/m $\qquad AE = 44\ 419\ 008$ N

1	2	3	4	5	6	7	8	9
H_1, N	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$ (5)	$\frac{2H_1}{w}$	(6) (7)	$\phi = L_0 -$ (8), m
13 500	3 676.546 478	0.999 622	3 675.156 743	0.272 234	0.268 979	1 290.156 1	347.02	3.48
15 750	3 676.546 478	.999 673	3 675.344 247	.233 355	.231 287	1 505.182 1	348.13	2.37
18 000	3 676.546 478	.999 723	3 675.528 075	.204 196	.202 803	1 720.208 1	348.86	1.64
21 000	3 676.546 478	.999 791	3 675.778 080	.175 037	.174 155	2 006.909 5	349.51	0.99
25 000	3 676.546 478	.999 881	3 676.108 969	.147 044	.146 519	2 389.178 0	350.06	0.44
30 292	3 676.546 478	1.000 000	3 676.546 478	.121 370	.121 074	2 894.919 2	350.4994	0.00
31 500	3 676.546 478	1.000 027	3 676.645 745	.116 719	.116 456	3 010.364 3	350.57	−0.07
36 000	3 676.546 478	1.000 129	3 677.020 752	.102 139	.101 962	3 440.416 3	350.79	−0.29
40 500	3 676.546 478	1.000 230	3 677.392 084	.090 800	.090 676	3 870.468 3	350.96	−0.46
45 000	3 676.546 478	1.000 331	3 677.763 415	.081 728	.081 637	4 300.520 4	351.08	−0.58
49 500	3 676.546 478	1.000 432	3 678.134 746	.074 306	.074 238	4 730.572 4	351.19	−0.69
54 000	3 676.546 478	1.000 534	3 678.509 754	.068 121	.068 068	5 160.624 4	351.27	−0.77
58 500	3 676.546 478	1.000 635	3 678.881 085	.062 887	.062 846	5 590.676 5	351.35	−0.85
60 584	3 676.546 478	1.000 682	3 679.053 883	.060 726	.060 689	5 789.838 3	351.38	−0.88
63 000	3 676.546 478	1.000 736	3 679.252 416	.058 401	.058 368	6 020.728 5	351.42	−0.92
67 500	3 676.546 478	1.000 838	3 679.627 424	.054 513	.054 486	6 450.780 5	351.48	−0.98
72 000	3 676.546 478	1.000 939	3 679.998 755	.051 111	.051 089	6 880.832 6	351.53	−1.03
76 500	3 676.546 478	1.001 040	3 680.370 086	.048 109	.048 090	7 310.884 6	351.58	−1.08
81 000	3 676.546 478	1.001 142	3 680.745 094	.045 441	.045 425	7 740.936 7	351.63	−1.13
85 500	3 676.546 478	1.001 243	3 681.116 425	.043 054	.043 041	8 170.988 7	351.69	−1.19
90 000	3 676.546 478	1.001 344	3 681.487 756	.040 905	.040 894	8 601.040 7	351.73	−1.23
94 500	3 676.546 478	1.001 446	3 681.862 764	.038 962	.038 952	9 031.092 8	351.78	−1.28
99 000	3 676.546 478	1.001 547	3 682.234 095	.037 194	.037 185	9 461.144 8	351.81	−1.31
103 500	3 676.546 478	1.001 648	3 682.605 427	.035 581	.035 573	9 891.196 8	351.86	−1.36
108 000	3 676.546 478	1.001 749	3 682.976 758	.034 102	.034 095	10 321.248 9	351.90	−1.40
112 500	3 676.546 478	1.001 851	3 683.351 766	.032 741	.032 735	10 751.300 9	351.94	−1.44

Numbers in parenthesis are column numbers.

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Table 15.–*H curve computations for example problem No. 2–unbalanced no-load condition (U.S. customary)*

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1} \right]$$

H_0 = 6810 lb L_0 = 1150 ft w = 1.434 lb/ft AE = 9 985 800 lb

1	2	3	4	5	6	7	8	9	10
H_1, lb	$H_0 \sinh - \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$ (5)	$\frac{2H_1}{w}$	(6) (7)	$\phi = L_0 -$ (8), ft	$\phi = L_0 -$ (8), in
3 000	826.564 130	0.999 618	826.248 383	0.275 416	0.272 048	4 184.100 4	1138.28	11.72	140.64
3 500	826.564 130	.999 685	826.303 762	.236 087	.233 947	4 881.450 5	1142.00	8.00	96.00
4 000	826.564 130	.999 719	826.331 866	.206 583	.205 141	5 578.800 5	1144.44	5.56	66.72
5 000	826.564 130	.999 819	826.414 522	.165 283	.164 540	6 973.500 7	1147.42	2.58	30.96
6 000	826.564 130	.999 919	826.497 178	.137 750	.137 318	8 368.200 8	1149.10	0.90	10.80
6 810	826.564 130	1.000 000	826.564 130	.121 375	.121 079	9 497.908 0	1149.9972	0.00	0.00
7 000	826.564 130	1.000 019	826.579 835	.118 083	.117 810	9 762.901 0	1150.17	-0.17	-2.04
8 000	826.564 130	1.000 119	826.662 491	.103 333	.103 150	11 157.601 1	1150.91	-0.91	-10.92
9 000	826.564 130	1.000 219	826.745 148	.091 861	.091 732	12 552.301 3	1151.45	-1.45	-17.40
10 000	826.564 130	1.000 319	826.827 804	.082 683	.082 589	13 947.001 4	1151.87	-1.87	-22.44
11 000	826.564 130	1.000 420	826.911 287	.075 174	.075 103	15 341.701 5	1152.21	-2.21	-26.52
12 000	826.564 130	1.000 520	826.993 943	.068 916	.068 862	16 736.401 7	1152.50	-2.50	-30.00
13 000	826.564 130	1.000 620	827.076 600	.063 621	.063 578	18 131.101 8	1152.74	-2.74	-32.88
13 620	826.564 130	1.000 682	827.127 847	.060 729	.060 692	18 995.815 9	1152.89	-2.89	-34.68
14 000	826.564 130	1.000 720	827.159 256	.059 083	.059 049	19 525.802 0	1152.98	-2.98	-35.76
15 000	826.564 130	1.000 820	827.241 913	.055 149	.055 121	20 920.502 1	1153.16	-3.16	-37.92
16 000	826.564 130	1.000 920	827.324 569	.051 708	.051 685	22 315.202 2	1153.36	-3.36	-40.32
17 000	826.564 130	1.001 020	827.407 225	.048 671	.048 652	23 709.902 4	1153.53	-3.53	-42.36
18 000	826.564 130	1.001 121	827.490 708	.045 972	.045 956	25 104.602 5	1153.71	-3.71	-44.52
19 000	826.564 130	1.001 221	827.573 365	.043 556	.043 542	26 499.302 7	1153.83	-3.83	-45.96
20 000	826.564 130	1.001 321	827.656 021	.041 383	.041 371	27 894.002 8	1154.00	-4.00	-48.00
21 000	826.564 130	1.001 421	827.738 678	.039 416	.039 406	29 288.702 9	1154.15	-4.15	-49.80
22 000	826.564 130	1.001 521	827.821 334	.037 628	.037 619	30 683.403 1	1154.28	-4.28	-51.36
23 000	826.564 130	1.001 621	827.903 990	.035 996	.035 988	32 078.103 2	1154.43	-4.43	-53.16
24 000	826.564 130	1.001 721	827.986 647	.034 499	.034 492	33 472.803 3	1154.54	-4.54	-54.48

Numbers in parenthesis are column numbers.

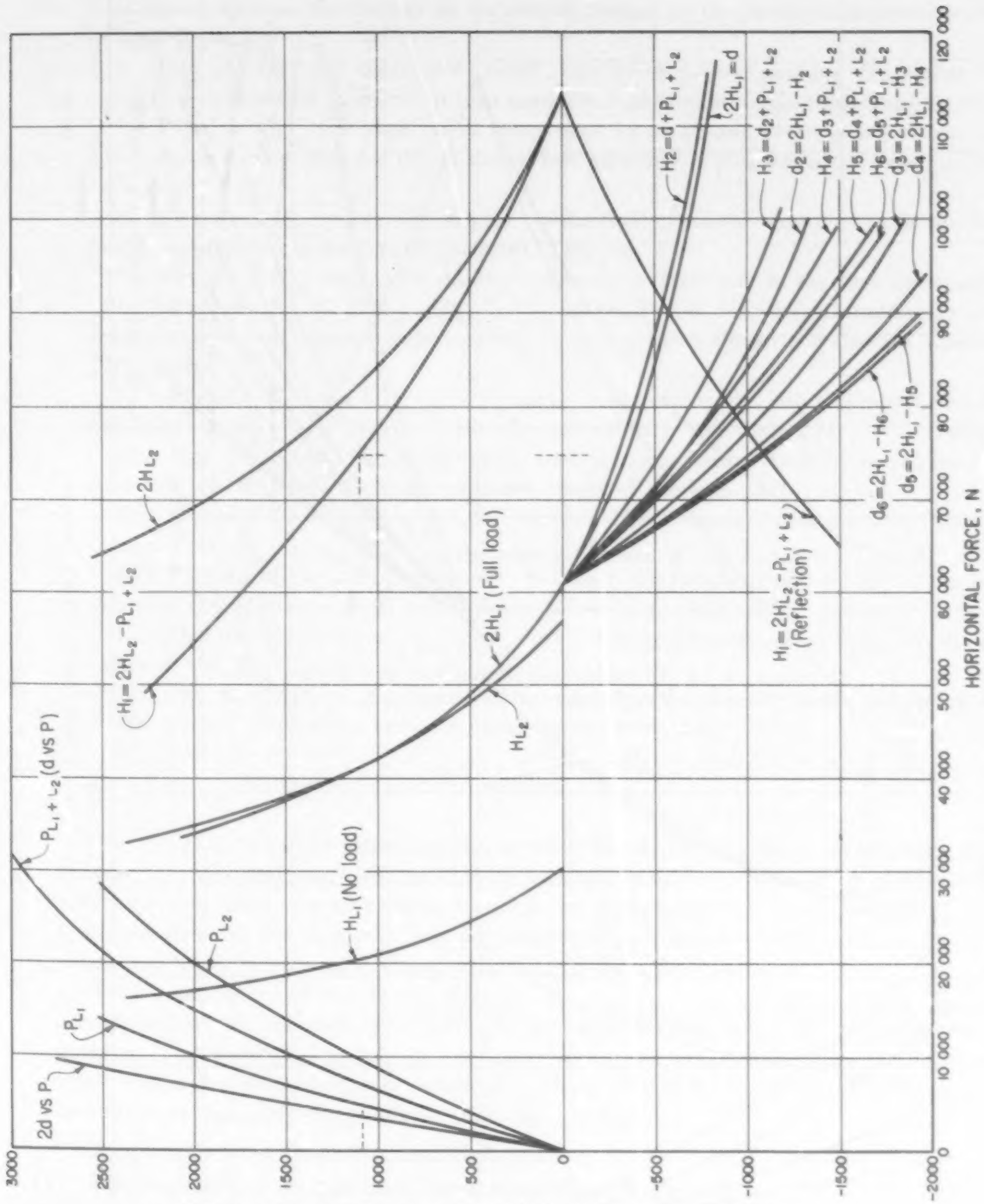

Figure 34.–Graphical solution of unbalanced condition (metric). 104-D-1064.

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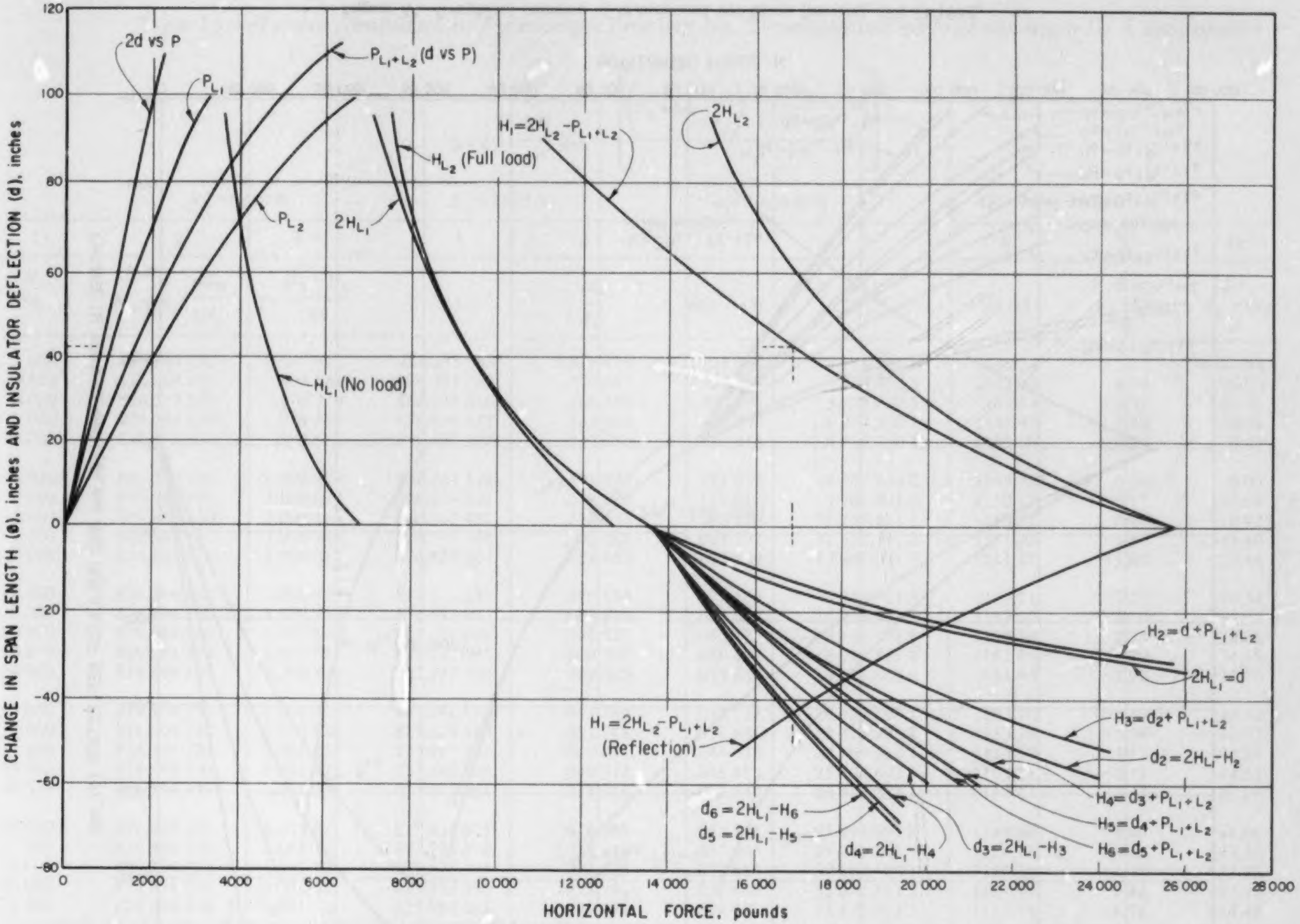


Figure 35.–Graphical solution of unbalanced condition (U.S. customary). 104-D-1065.

5. Plot the $2d$ versus P curve using table 10 or 11. Since the insulator strings at each end of the span with iced conductors, swing a like amount toward each other, this curve is necessary to read the change in horizontal tension at the insulator between loaded and unloaded spans.

6. Plot the H_{L_1} (no load) curve using table 14 or 15 and plotting H_1 versus ϕ. This curve is not needed for this solution, but normally is plotted in the first quadrant for reference.

7. Plot the H_{L_2} (full load) curve using table 12 or 13 and plotting H_1 versus ϕ. This curve also is not needed for this solution, but normally is plotted in the first quadrant for reference.

8. Plot the $2H_{L_1}$ curve (for duplex conductors). Plot this curve in both the first and fourth quadrants. In the fourth quadrant, $2H_{L_1} = d$.

9. Plot the $2H_{L_2}$ curve (for duplex conductors). Plot only in the first quadrant.

10. Plot the $H_1 = 2H_{L_2} - P_{L_1 + L_2}$ curve. This is done by subtracting graphically, point by point, the abscissa values of the $P_{L_1 + L_2}$ curve from the abscissa values of the $2H_{L_2}$ curve.

11. Plot the $H_2 = d + P_{L_1 + L_2}$ curve. Add graphically, point by point, the abscissa values of the $P_{L_1 + L_2}$ curve to the abscissa values of the basic $2H_{L_1} = d$ curve.

12. Plot the $d_2 = 2H_{L_1} - H_2$ curve. Subtract graphically, point by point, the ordinate values of the H_2 curve from the ordinate values of the basic $2H_{L_1}$ curve.

13. Plot the $H_3 = d_2 + P_{L_1 + L_2}$ curve. Add graphically, point by point, the abscissa values of the $P_{L_1 + L_2}$ curve to the abscissa values of the d_2 curve.

14. Plot the $d_3 = 2H_{L_1} - H_3$ curve. Subtract graphically, point by point, the ordinate values of the H_3 curve from the ordinate values of the basic $2H_{L_1}$ curve.

15. Plot the $H_4 = d_3 + P_{L_1 + L_2}$ curve. Add graphically, point by point, the abscissa values of the $P_{L_1 + L_2}$ curve to the abscissa values of the d_3 curve.

16. Plot $d_4 = 2H_{L_1} - H_4$ curve. Subtract graphically, point by point, the ordinate values of the H_4 curve from the ordinate values of the basic $2H_{L_1}$ curve.

17. Plot the $H_5 = d_4 + P_{L_1 + L_2}$, $d_5 = 2H_{L_1} - H_5$, $H_6 = d_5 + P_{L_1 + L_2}$, and $d_6 = 2H_{L_1} - H_6$ curves in a similar manner.

The d curves converge quite rapidly, so that the d_6 curve gives a satisfactory degree of accuracy for this problem; however, if more accuracy is desired, the plotting of H and d curves may continue until two successive d curves are essentially the same curve. If desired, an approximation of the d_n curve may be computed as indicated on figure 16 of the broken conductor thesis in appendix A, and then plotted for a final value.

Draw a reflection of the $H_1 = 2H_{L_2} - P_{L_1 + L_2}$ curve in the fourth quadrant. The intersection of the reflected curve with the d_6 curve is taken as an acceptable answer to the problem. The horizontal tension in the conductor at the structure between the full-load span and the adjacent no-load span is indicated as about 74 800 N (16 800 lb). The insulator string deflection at that structure is about 1090 mm (42.8 in).

17. Insulator Effect on Sag and Tension in Short Spans.–In short, dead-ended spans, such as approach spans to switchyards and substations, the insulator strings may have considerable effect on the sag and tension in the conductors. This is especially true when the conductors are strung at reduced tensions. Based on the same maximum tension at full-load conditions (ice and wind loading in accordance with applicable electrical safety codes), the tension at no-load conditions (no ice and no wind) may actually be as much as twice that calculated by normal methods without considering the insulators. The total sag of conductors and insulators will also be different than the sag calculated without taking the insulators into account.

A method of calculating the insulator effect in steeply inclined spans, where the conductor low point is outside the span, is given in reference [5]. Another method has been developed to determine the insulator effect for approximately level spans and is satisfactory for spans which are not inclined by more than 20 percent. This method of calculating the insulator effect is based on the catenary equations for transmission lines. The conductor assumes one catenary, and the insulator string another catenary. The two catenaries are tangent at the point where the conductor is attached to the insulators. For equilibrium, the horizontal tensions in the two catenaries must be equal. Figure 36 shows the nomenclature used in describing the procedure for this method.

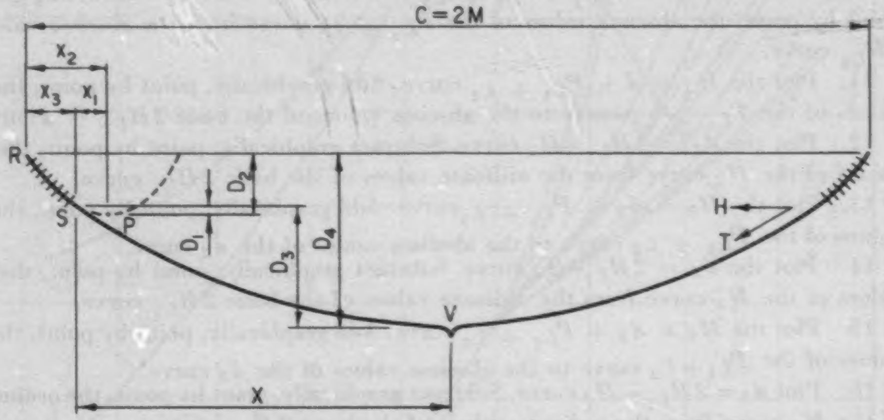


Figure 36.–Nomenclature for determining insulator effect on sag and tension in short spans. 104-D-1066.

Nomenclature description:

C = $2M$ = inclined length of span, m (ft)
D_1 = sag at center of insulator catenary, below end of insulator string, mm (ft)
D_2 = sag at center of insulator catenary, below support point, mm (ft)
D_3 = conductor sag, below end of insulator string, mm (ft)
D_4 = total sag, insulators plus conductor, mm (ft)
L = SV = arc length of one-half the conductor span, m (ft)
Lu = unstressed arc length of L, m (ft)
RS = length of insulator string, m (ft)
SP = arc length from insulator catenary center to end of insulator string, m (ft)
A = cross-sectional area of conductor, mm² (in²)
E = modulus of elasticity of conductor, GPa (lb/ft²)
e = temperature coefficient of conductor
a_1 = parameter of the catenary described by the conductor
a_2 = parameter of the catenary described by the insulator string

H = horizontal component of tension in conductor, N (lb)
T = tension in conductor, N (lb)
W = linear force factor (weight per unit length) of insulator string, N/m (lb/ft)
W_1 = linear force factor of conductor, N/m (lb/ft)
X = $M - X_3$ = one-half the length of conductor span, m (ft)
X_3 = projected length of insulator string, m (ft)

Steps in the procedure are:

***Step 1.*–Calculate Lu, the unstressed arc length of L, for the required loading condition by using the following equations:**

$$a_1 = H/W_1, \text{ for conductor catenary} \tag{1}$$

$$a_2 = H/W, \text{ for insulator catenary} \tag{2}$$

$$X_1 = \frac{a_2 X}{a_1}, \text{ for this equation assume } X = (M - RS)\,(1.0005) \tag{3}$$

Assumption of an appropriate value for X at this point greatly simplifies the calculation of a more accurate value of X. The calculated value of X could be substituted in equation (3) and calculations repeated to obtain a still more accurate value; however, subsequent repetitive calculations increase the accuracy very little.

$$SP = a_2 \sinh \frac{X_1}{a_2} \tag{4}$$

$$RSP = RS + SP \tag{5}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} \tag{6}$$

$$X_3 = X_2 - X_1 \tag{7}$$

$$X = M - X_3 \tag{8}$$

$$L = a_1 \sinh \frac{X}{a_1} \tag{9}$$

$$Lu = L - \frac{W_1 (a_1)^2}{2AE} \left(\frac{X}{a_1} + \sinh \frac{X}{a_1} \cosh \frac{X}{a_1} \right) \tag{10}$$

Step 2.–With a range of tensions (assume $H = T$) and corresponding unstressed arc lengths Lu, determine the temperatures for which the conductor would have these arc lengths:

Let:

t_0 = temperature at known conditions
Lu_0 = unstressed conductor arc length at known conditions
$t_1, t_2, \ldots t_n$ = temperatures at new conditions
$Lu_1, Lu_2, \ldots Lu_n$ = unstressed conductor arc lengths at new conditions

$$Lu_1 = Lu_0 + Lu_0 e\,(t_1 - t_0) \qquad (11)$$

$$Lu_2 = Lu_0 + Lu_0 e\,(t_2 - t_0) \qquad (11)$$

$$Lu_n = Lu_0 + Lu_0 e\,(t_n - t_0) \qquad (11)$$

Step 3.–Plot tension against temperature corresponding to each unstressed arc length for each loading condition. From this plot, determine the tension at the desired temperatures. For each tension, calculate values for X, X_1, and X_2 using equations (1) through (8).

Step 4.–The total sag of the line, insulators plus conductor, is then determined:

$$D_1 = a_2 \left(\cosh \frac{X_1}{a_2} - 1\right) \qquad (12)$$

$$D_2 = a_2 \left(\cosh \frac{X_2}{a_2} - 1\right) \qquad (13)$$

$$D_3 = a_1 \left(\cosh \frac{X}{a_1} - 1\right) \qquad (14)$$

$$D_4 = D_3 + D_2 - D_1 \qquad (15)$$

Example

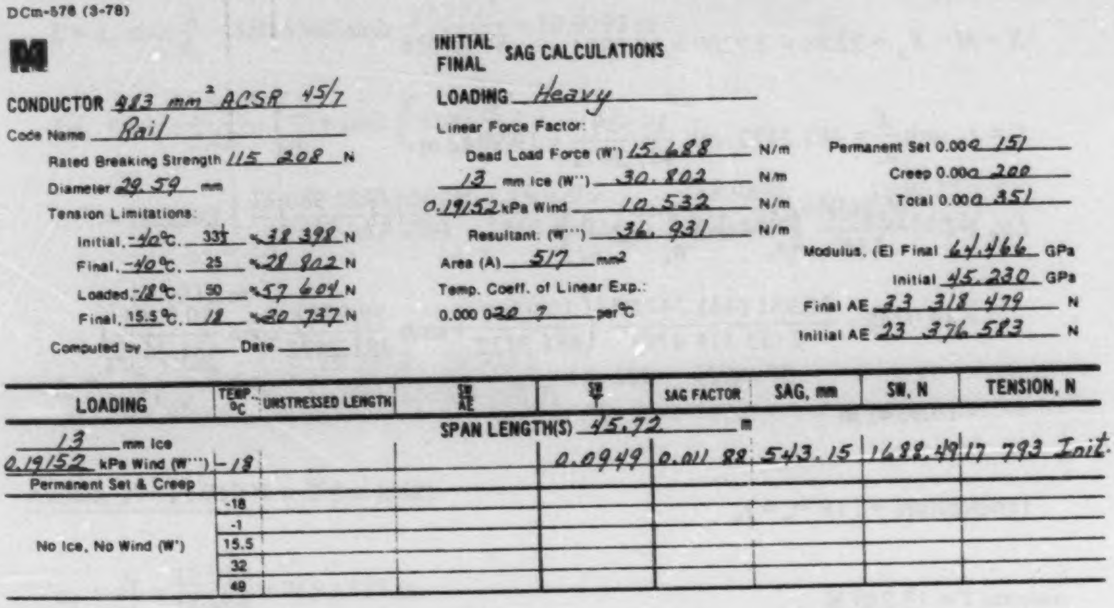
Assume: 483 mm² (954 kcmil), ACSR, 45/7 conductor with maximum tension of 17 793 N (4000 lb) under NESC heavy loading of 13-mm (1/2-in) ice, 0.19-kPa (4-lb/ft²) wind, plus constant at minus 18 °C (0 °F). Use a 45.72-m (150-ft) span with 15-unit tension insulator strings.

Insulator string data	Length m	Length (in)	Mass kg	Mass (lb)
15 insulator units	2.1908	86.25	74.84	165
Anchor shackle	0.0813	3.2	0.45	1.0
Ball-eye fitting	.0711	2.8	.68	1.5
Compression dead end	.5842	23.0	10.07	22.2
	2.9274 m	115.25 in	86.04 kg	189.7 lb

$$W = \frac{86.04}{2.9274} = 29.3912 \text{ kg/m} = 288.2292 \text{ N/m} \qquad W = \frac{(189.7)(12)}{115.25} = 19.75 \text{ lb/ft}$$

Metric

Figure 37 shows the metric sag and tension calculations.



DCm-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

CONDUCTOR 483 mm² ACSR 45/7
Code Name Rail
Rated Breaking Strength 115 208 N
Diameter 29.59 mm
Tension Limitations:
Initial, -40°C. 33⅓ % 38 398 N
Final, -40°C. 25 % 28 802 N
Loaded, -18°C. 50 % 57 604 N
Final, 15.5°C. 18 % 20 737 N
Computed by ______ Date ______

LOADING Heavy
Linear Force Factor:
Dead Load Force (W') 15.688 N/m
13 mm Ice (W'') 30.802 N/m
0.19152 kPa Wind 10.532 N/m
Resultant. (W''') 36.931 N/m
Area (A) 517 mm²
Temp. Coeff. of Linear Exp.:
0.000 020 7 per°C

Permanent Set 0.000 151
Creep 0.000 200
Total 0.000 351
Modulus, (E) Final 64.466 GPa
Initial 45.230 GPa
Final AE 33 318 479 N
Initial AE 23 376 583 N

LOADING	TEMP °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
SPAN LENGTH(S) 45.72 m								
13 mm Ice 0.19152 kPa Wind (W''')	-18			0.0949	0.011 88	543.15	1688.49	17 793 Init.
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							

Figure 37.–Sag and tension calculation form for insulator effect problem (metric).

$$H = T - W_1 (\text{sag}) = 17\,793 - 36.931\,(0.5432) = 17\,772.94 \text{ N}$$

$$a_1 = \frac{H}{W_1} = \frac{17\,772.94}{36.931} = 481.2472 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{17\ 772.94}{288.2292} = 61.6625 \text{ m}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{61.6625\,(22.86 - 2.9274)\,(1.0005)}{481.2472} = 2.5553 \text{ m}$$

$$SP = a_2 \ \sinh \frac{X_1}{a_2} = 61.6625 \sinh \frac{2.5553}{61.6625} = 2.5560 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 2.5560 = 5.4834 \text{ m}$$

$$X_2 = a_2 \ \sinh^{-1} \frac{RSP}{a_2} = 61.6625 \sinh^{-1} \frac{5.4834}{61.6625} = 5.4762 \text{ m}$$

$$X_3 = X_2 - X_1 = 5.4762 - 2.5553 = 2.9209 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9209 = 19.9391 \text{ m}$$

$$L = a_1 \ \sinh \frac{X}{a_1} = 481.2472 \sinh \frac{19.9391}{481.2472} = 19.9448 \text{ m}$$

$$Lu_0 = L - \frac{W_1\,(a_1)^2}{2AE}\left(\frac{X}{a_1} + \sinh \frac{X}{a_1} \cosh \frac{X}{a_1}\right)$$

$$= 19.9448 - \frac{36.931\,(481.2472)^2}{2\,(33\ 318\ 479)}\left(\frac{19.9391}{481.2472} + \sinh \frac{19.9391}{481.2472} \cosh \frac{19.9391}{481.2472}\right)$$

$$= 19.9342 \text{ m}$$

Temperature $= -18\ ^{\circ}\text{C} = t_0$

Assume $T = 13\ 345$ N

$$a_1 = \frac{H}{W_1} = \frac{13\ 345}{15.688} = 850.6502 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{13\ 345}{288.2292} = 46.3000 \text{ m}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{46.3000\,(22.86 - 2.9274)\,(1.0005)}{850.6502} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 46.3000 \sinh\frac{1.0855}{46.3000} = 1.0856 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0856 = 4.0130 \text{ m}$$

$$X_2 = a_2 \sinh^{-1}\frac{RSP}{a_2} = 46.3000 \sinh^{-1}\frac{4.0130}{46.3000} = 4.0080 \text{ m}$$

$$X_3 = X_2 - X_1 = 4.0080 - 1.0855 = 2.9225 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9225 = 19.9375 \text{ m}$$

$$L = a_1 \sinh\frac{X}{a_1} = 850.6502 \sinh\frac{19.9375}{850.6502} = 19.9393 \text{ m}$$

$$Lu_1 = L - \frac{W_1\,(a_1)^2}{2AE}\left(\frac{X}{a_1} + \sinh\frac{X}{a_1}\cosh\frac{X}{a_1}\right)$$

$$= 19.9393 - \frac{15.688\,(850.6502)^2}{2\,(33\,318\,479)}\left(\frac{19.9375}{850.6502} + \sinh\frac{19.9375}{850.6502}\cosh\frac{19.9375}{850.6502}\right)$$

$$= 19.9313 \text{ m}$$

$$t_1 = \frac{Lu_1 - Lu_0}{Lu_0\,e} + t_0 = \frac{19.9313 - 19.9342}{19.9342\,(0.000\,020\,7)} + (-18) = -25.03\ ^{\circ}\text{C}$$

Assume $T = 12\,010$ N $\approx H$ (no load)

$$a_1 = \frac{H}{W_1} = \frac{12\,010}{15.688} = 765.5533 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{12\,010}{288.2292} = 41.6682 \text{ m}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{41.6682\,(22.86 - 2.9274)\,(1.0005)}{765.5533} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 41.6682 \sinh \frac{1.0855}{41.6682} = 1.0856 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0856 = 4.0130 \text{ m}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 41.6682 \sinh^{-1} \frac{4.0130}{41.6682} = 4.0068 \text{ m}$$

$$X_3 = X_2 - X_1 = 4.0068 - 1.0855 = 2.9213 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9213 = 19.9387 \text{ m}$$

$$L = a_1 \sinh \frac{X}{a_1} = 765.5533 \sinh \frac{19.9387}{765.5533} = 19.9410 \text{ m}$$

$$Lu_2 = L - \frac{W_1 (a_1)^2}{2AE} \left(\frac{X}{a_1} + \sinh \frac{X}{a_1} \cosh \frac{X}{a_1} \right)$$

$$= 19.9410 - \frac{15.688\ (765.5533)^2}{2\ (33\ 318\ 479)} \left(\frac{19.9387}{765.5533} + \sinh \frac{19.9387}{765.5533} \cosh \frac{19.9387}{765.5533} \right)$$

$$= 19.9338 \text{ m}$$

$$t_2 = \frac{Lu_2 - Lu_0}{Lu_0 e} + t_0 = \frac{19.9338 - 19.9342}{19.9342\ (0.000\ 020\ 7)} + (-18) = -18.97\ ^{\circ}\text{C}$$

Similar calculations were made for five additional assumed tensions, and the resulting temperatures were:

Assumed $T \approx H$ (no load), N	Temperature, °C
10 675	$t_3 = -11.94$
9 341	$t_4 = -2.23$
8 007	$t_5 = 11.58$
6 672	$t_6 = 33.13$
6 227	$t_7 = 43.31$

The resulting temperatures are plotted against the assumed tensions on figure 38. Using this figure, determine the tensions for the desired temperatures and proceed in finding the total sag of the line.

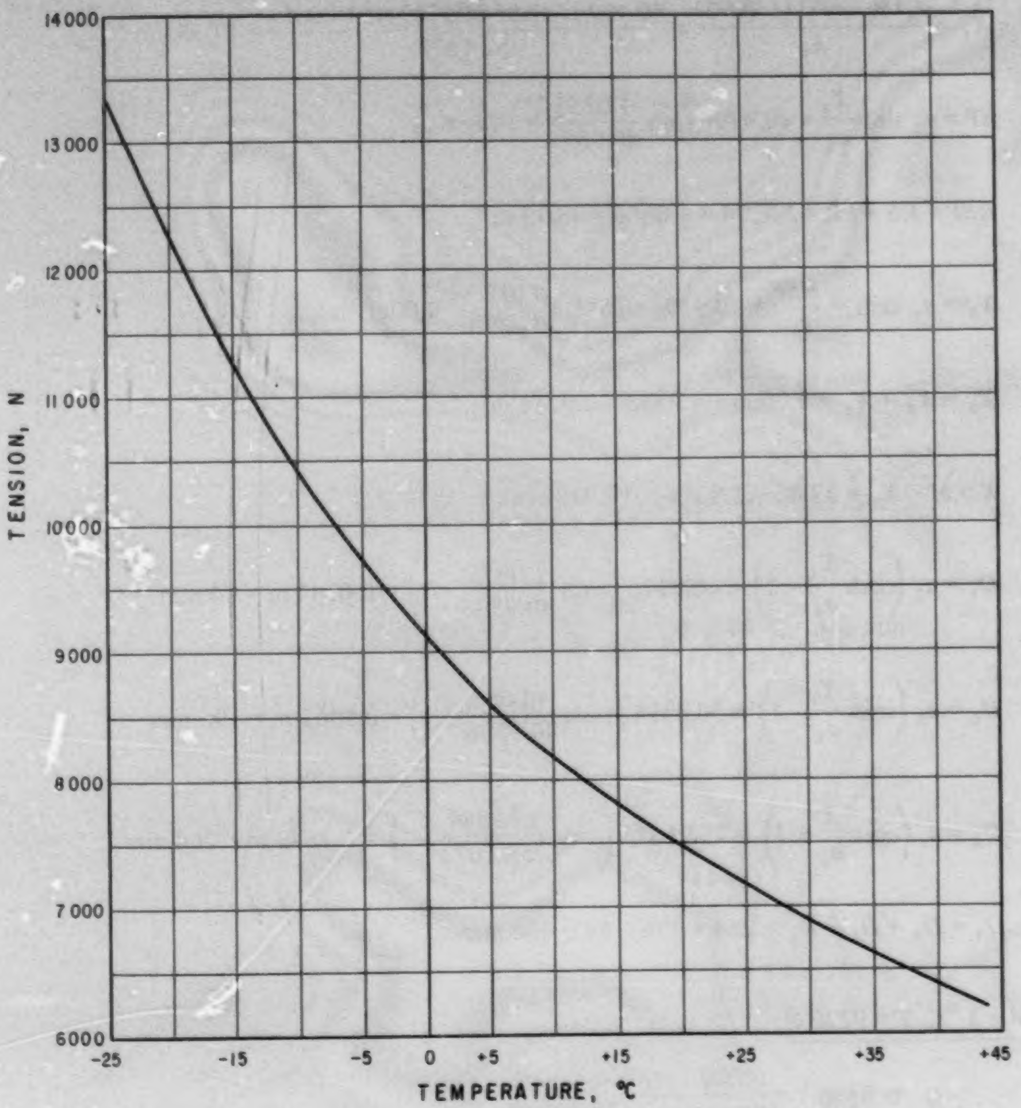


Figure 38.–Tension-temperature curve for insulator effect problem (metric). 104-D-1067.

At - 18 °C, T = 11 800 N

$$a_1 = \frac{H}{W_1} = \frac{11\,800}{15.688} = 752.1673 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{11\,800}{288.2292} = 40.9396 \text{ m}$$

$$X_1 = \frac{a_2(M - RS)(1.0005)}{a_1} = \frac{40.9396\,(22.86 - 2.9274)\,(1.0005)}{752.1673} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 40.9396 \sinh\frac{1.0855}{40.9396} = 1.0856 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0856 = 4.013 \text{ m}$$

$$X_2 = a_2 \sinh^{-1}\frac{RSP}{a_2} = 40.9396 \sinh^{-1}\frac{4.013}{40.9396} = 4.0066 \text{ m}$$

$$X_3 = X_2 - X_1 = 4.0066 - 1.0855 = 2.9211 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9211 = 19.9389 \text{ m}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 40.9396\left(\cosh\frac{1.0855}{40.9396} - 1\right) = 0.0144 \text{ m} = 14 \text{ mm}$$

$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 40.9396\left(\cosh\frac{4.0066}{40.9396} - 1\right) = 0.1962 \text{ m} = 196 \text{ mm}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 752.1673\left(\cosh\frac{19.9389}{752.1673} - 1\right) = 0.2643 \text{ m} = 264 \text{ mm}$$

$$D_4 = D_3 + D_2 - D_1 = 264 + 196 - 14 = 446 \text{ mm}$$

At - 1 °C, $T = 9220$ N

$$a_1 = \frac{H}{W_1} = \frac{9220}{15.688} = 587.7104 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{9220}{288.2292} = 31.9884 \text{ m}$$

$$X_1 = \frac{a_2(M - RS)(1.0005)}{a_1} = \frac{31.9884\,(22.86 - 2.9274)\,(1.0005)}{587.7104} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 31.9884 \sinh\frac{1.0855}{31.9884} = 1.0857 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0857 = 4.0131 \text{ m}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 31.9884 \sinh^{-1} \frac{4.0131}{31.9884} = 4.0026 \text{ m}$$

$$X_3 = X_2 - X_1 = 4.0026 - 1.0855 = 2.9176 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9176 = 19.9424 \text{ m}$$

$$D_1 = a_2 \left(\cosh \frac{X_1}{a_2} - 1\right) = 31.9884 \left(\cosh \frac{1.0855}{31.9884} - 1\right) = 0.0184 \text{ m} = 18 \text{ mm}$$

$$D_2 = a_2 \left(\cosh \frac{X_2}{a_2} - 1\right) = 31.9884 \left(\cosh \frac{4.0026}{31.9884} - 1\right) = 0.2507 \text{ m} = 251 \text{ mm}$$

$$D_3 = a_1 \left(\cosh \frac{X}{a_1} - 1\right) = 587.7104 \left(\cosh \frac{19.9424}{587.7104} - 1\right) = 0.3384 \text{ m} = 338 \text{ mm}$$

$$D_4 = D_3 + D_2 - D_1 = 338 + 251 - 18 = 571 \text{ mm}$$

At 15.5 °C, $T = 7740$ N

$$a_1 = \frac{H}{W_1} = \frac{7740}{15.688} = 493.3707 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{7740}{288.2292} = 26.8536 \text{ m}$$

$$X_1 = \frac{a_2 (M - RS)(1.0005)}{a_1} = \frac{26.8536\,(22.86 - 2.9274)\,(1.0005)}{493.3707} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 26.8536 \sinh \frac{1.0855}{26.8536} = 1.0858 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0858 = 4.0132 \text{ m}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 26.8536 \sinh^{-1} \frac{4.0132}{26.8536} = 3.9984 \text{ m}$$

$$X_3 = X_2 - X_1 = 3.9984 - 1.0855 = 2.9129 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9129 = 19.9471 \text{ m}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 26.8536\left(\cosh\frac{1.0855}{26.8536} - 1\right) = 0.0219 \text{ m} = 22 \text{ mm}$$

$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 26.8536\left(\cosh\frac{3.9984}{26.8536} - 1\right) = 0.2982 \text{ m} = 298 \text{ mm}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 493.3707\left(\cosh\frac{19.9471}{493.3707} - 1\right) = 0.4033 \text{ m} = 403 \text{ mm}$$

$$D_4 = D_3 + D_2 - D_1 = 403 + 298 - 22 = 679 \text{ mm}$$

At 32 °C, $T = 6760$ N

$$a_1 = \frac{H}{W_1} = \frac{6760}{15.688} = 430.9026 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{6760}{288.2292} = 23.4536 \text{ m}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{23.4536\,(22.86 - 2.9274)\,(1.0005)}{430.9026} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 23.4536 \sinh\frac{1.0855}{23.4536} = 1.0859 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0859 = 4.0133 \text{ m}$$

$$X_2 = a_2 \sinh^{-1}\frac{RSP}{a_2} = 23.4536 \sinh^{-1}\frac{4.0133}{23.4536} = 3.9940 \text{ m}$$

$$X_3 = X_2 - X_1 = 3.9940 - 1.0855 = 2.9085 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9085 = 19.9515 \text{ m}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 23.4536\left(\cosh\frac{1.0855}{23.4536} - 1\right) = 0.0251 \text{ m} = 25 \text{ mm}$$

$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 23.4536\left(\cosh\frac{3.9940}{23.4536} - 1\right) = 0.3409 \text{ m} = 341 \text{ mm}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 430.9026\left(\cosh\frac{19.9515}{430.9026} - 1\right) = 0.4620 \text{ m} = 462 \text{ mm}$$

$$D_4 = D_3 + D_2 - D_1 = 462 + 341 - 25 = 778 \text{ mm}$$

At 43 °C, $T = 6260$ N

$$a_1 = \frac{H}{W_1} = \frac{6260}{15.688} = 399.0311 \text{ m}$$

$$a_2 = \frac{H}{W} = \frac{6260}{288.2292} = 21.7188 \text{ m}$$

$$X_1 = \frac{a_2(M - RS)(1.0005)}{a_1} = \frac{21.7188\,(22.86 - 2.9274)\,(1.0005)}{399.0311} = 1.0855 \text{ m}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 21.7188 \sinh\frac{1.0855}{21.7188} = 1.0860 \text{ m}$$

$$RSP = RS + SP = 2.9274 + 1.0860 = 4.0134 \text{ m}$$

$$X_2 = a_2 \sinh^{-1}\frac{RSP}{a_2} = 21.7188 \sinh^{-1}\frac{4.0134}{21.7188} = 3.9909 \text{ m}$$

$$X_3 = X_2 - X_1 = 3.9909 - 1.0855 = 2.9054 \text{ m}$$

$$X = M - X_3 = 22.86 - 2.9054 = 19.9546 \text{ m}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 21.7188\left(\cosh\frac{1.0855}{21.7188} - 1\right) = 0.0271 \text{ m} = 27 \text{ mm}$$

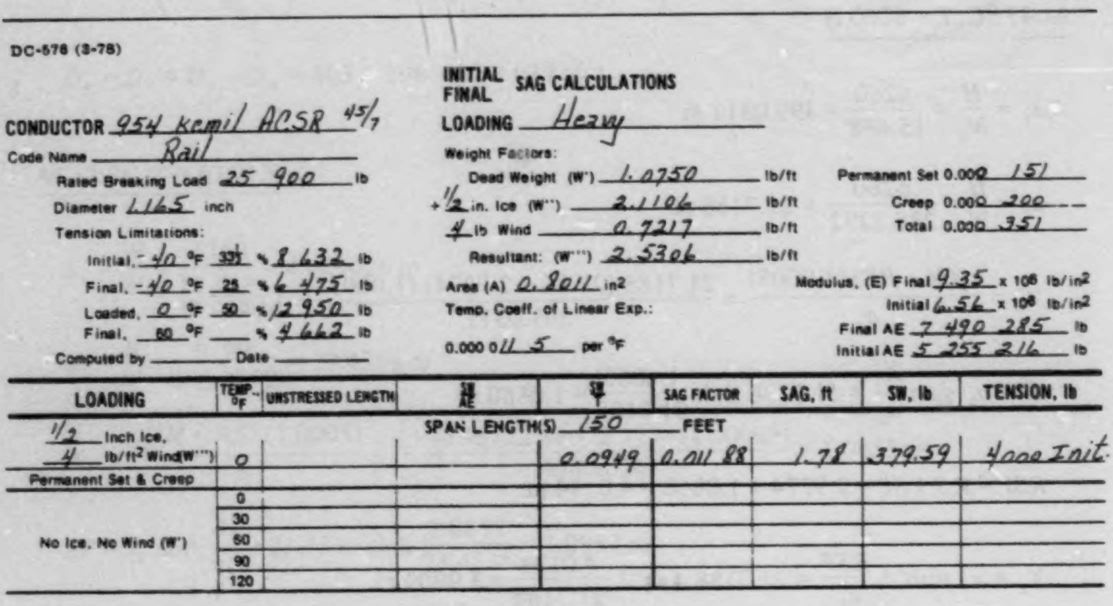
$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 21.7188\left(\cosh\frac{3.9909}{21.7188} - 1\right) = 0.3677 \text{ m} = 368 \text{ mm}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 399.0311\left(\cosh\frac{19.9546}{399.0311} - 1\right) = 0.4990 \text{ m} = 499 \text{ mm}$$

$$D_4 = D_3 + D_2 - D_1 = 499 + 368 - 27 = 840 \text{ mm}$$

U.S. Customary

Figure 39 shows the U.S. customary sag and tension computations.



DC-576 (3-78)

INITIAL / FINAL SAG CALCULATIONS

CONDUCTOR 954 kcmil ACSR 45/7

Code Name Rail

Rated Breaking Load 25 900 lb

Diameter 1.165 inch

Tension Limitations:

Initial, -40 °F 33⅓ % 8 632 lb

Final, -40 °F 25 % 6 475 lb

Loaded, 0 °F 50 % 12 950 lb

Final, 60 °F ___ % 4 662 lb

Computed by ______ Date ______

LOADING Heavy

Weight Factors:

Dead Weight (W') 1.0750 lb/ft

+ 1/2 in. Ice (W'') 2.1106 lb/ft

4 lb Wind 0.7217 lb/ft

Resultant: (W''') 2.5306 lb/ft

Area (A) 0.8011 in2

Temp. Coeff. of Linear Exp.:

0.000 011 5 per °F

Permanent Set 0.000 151

Creep 0.000 200

Total 0.000 351

Modulus, (E) Final 9.35 x 10⁶ lb/in2

Initial 6.56 x 10⁶ lb/in2

Final AE 7 490 285 lb

Initial AE 5 255 216 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
			SPAN LENGTH(S) 150 FEET					
1/2 Inch Ice, 4 lb/ft2 Wind(W''')	0			0.0949	0.011 88	1.78	379.59	4000 Init.
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120							

Figure 39.–Sag and tension calculation form for insulator effect problem (U.S. customary).

$$H = T - W_1(\text{sag}) = 4000 - 2.5306\,(1.78) = 3995.5393 \text{ lb}$$

$$a_1 = \frac{H}{W_1} = \frac{3995.5393}{2.5306} = 1578.8901 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{3995.5393}{19.75} = 202.3058 \text{ ft}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{202.3013\ (75 - 9.6)\ (1.0005)}{1578.8901} = 8.3838 \text{ ft}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 202.3058 \sinh \frac{8.3838}{202.3058} = 8.3862 \text{ ft}$$

$$RSP = RS + SP = 9.6 + 8.3862 = 17.9862 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 202.3058 \sinh^{-1} \frac{17.9862}{202.3058} = 17.9626 \text{ ft}$$

$$X_3 = X_2 - X_1 = 17.9626 - 8.3838 = 9.5788 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5788 = 65.4212 \text{ ft}$$

$$L = a_1 \sinh \frac{X}{a_1} = 1578.8901 \sinh \frac{65.4212}{1578.8901} = 65.4399 \text{ ft}$$

$$Lu_0 = L - \frac{W_1\,(a_1)^2}{2AE} \left(\frac{X}{a_1} + \sinh \frac{X}{a_1} \cosh \frac{X}{a_1}\right)$$

$$= 65.4399 - \frac{2.5306\ (1578.8901)^2}{2\ (7\ 490\ 285)} \left(\frac{65.4212}{1578.8901} + \sinh \frac{65.4212}{1578.8901} \cosh \frac{65.4212}{1578.8901}\right)$$

$$= 65.4050 \text{ ft}$$

Temperature = 0 °F = t_0

Assume $T = 3000$ lb ≈ H (no load)

$$a_1 = \frac{H}{W_1} = \frac{3000}{1.075} = 2790.6977 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{3000}{19.75} = 151.8987 \text{ ft}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{151.8987\ (75 - 9.60)\ (1.0005)}{2790.6977} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 151.8987 \sinh \frac{3.5615}{151.8987} = 3.5618 \text{ ft}$$

$$RSP = RS + SP = 9.6 + 3.5618 = 13.1618 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 151.8987 \sinh^{-1} \frac{13.1618}{151.8987} = 13.1454 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.1454 - 3.5615 = 9.5839 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5839 = 65.4161 \text{ ft}$$

$$L = a_1 \sinh \frac{X}{a_1} = 2790.6977 \sinh \frac{65.4161}{2790.6977} = 65.4221 \text{ ft}$$

$$Lu_1 = L - \frac{W_1 (a_1)^2}{2AE} \left(\frac{X}{a_1} + \sinh \frac{X}{a_1} \cosh \frac{X}{a_1} \right)$$

$$= 65.4221 - \frac{1.075\,(2790.6977)^2}{2\,(7\,490\,285)} \left(\frac{65.4161}{2790.6977} + \sinh \frac{65.4161}{2790.6977} \cosh \frac{65.4161}{2790.6977} \right)$$

$$= 65.3959 \text{ ft}$$

$$Lu_1 = Lu_0 + Lu_0 e (t_1 - t_0)$$

$$t_1 = \frac{Lu_1 - Lu_0}{Lu_0 e} + t_0 = \frac{65.3959 - 65.4050}{65.4050\,(0.000\,011\,5)} + 0 = -12.10\ {}^\circ\text{F}$$

Assume $T = 2700$ lb $\approx H$ (no load)

$$a_1 = \frac{H}{W_1} = \frac{2700}{1.075} = 2511.6279 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{2700}{19.75} = 136.7089 \text{ ft}$$

$$X_1 = \frac{a_2 (M - RS)(1.0005)}{a_1} = \frac{136.7089\,(75 - 9.6)\,(1.0005)}{2511.6279} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 136.7089 \sinh \frac{3.5615}{136.7089} = 3.5619 \text{ ft}$$

$$RSP = RS + SP = 9.6 + 3.5619 = 13.1619 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 136.7089 \sinh^{-1} \frac{13.1619}{136.7089} = 13.1417 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.1417 - 3.5615 = 9.5802 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5802 = 65.4198 \text{ ft}$$

$$L = a_1 \sinh \frac{X}{a_1} = 2511.6279 \sinh \frac{65.4198}{2511.6279} = 65.4273 \text{ ft}$$

$$Lu_2 = L - \frac{W_1 (a_1)^2}{2AE} \left(\frac{X}{a_1} + \sinh \frac{X}{a_1} \cosh \frac{X}{a_1} \right)$$

$$= 65.4273 - \frac{1.075\ (2511.6279)^2}{2\,(7\ 490\ 285)} \left(\frac{65.4198}{2511.6279} + \sinh \frac{65.4198}{2511.6279} \cosh \frac{65.4198}{2511.6279} \right)$$

$$= 65.4037 \text{ ft}$$

$$t_2 = \frac{Lu_2 - Lu_0}{Lu_0\, e} + t_0 = \frac{65.4037 - 65.4050}{65.4050\ (0.000\ 011\ 5)} = -1.73\ ^\circ\text{F}$$

Similar calculations were made for five additional assumed tensions, and the resulting temperatures were:

Assumed $T \approx H$ (no load), lb	Temperature, °F
2400	$t_3 = 11.30$
2100	$t_4 = 28.72$
1800	$t_5 = 53.58$
1500	$t_6 = 92.53$
1400	$t_7 = 110.88$

The resulting temperatures are plotted against the assumed tensions on figure 40. Using this figure, determine the tensions for the desired temperatures and proceed in finding the total sag of the line.

At 0 °F, $T = 2645$ lb

$$a_1 = \frac{H}{W_1} = \frac{2645}{1.075} = 2460.4651 \text{ ft}$$

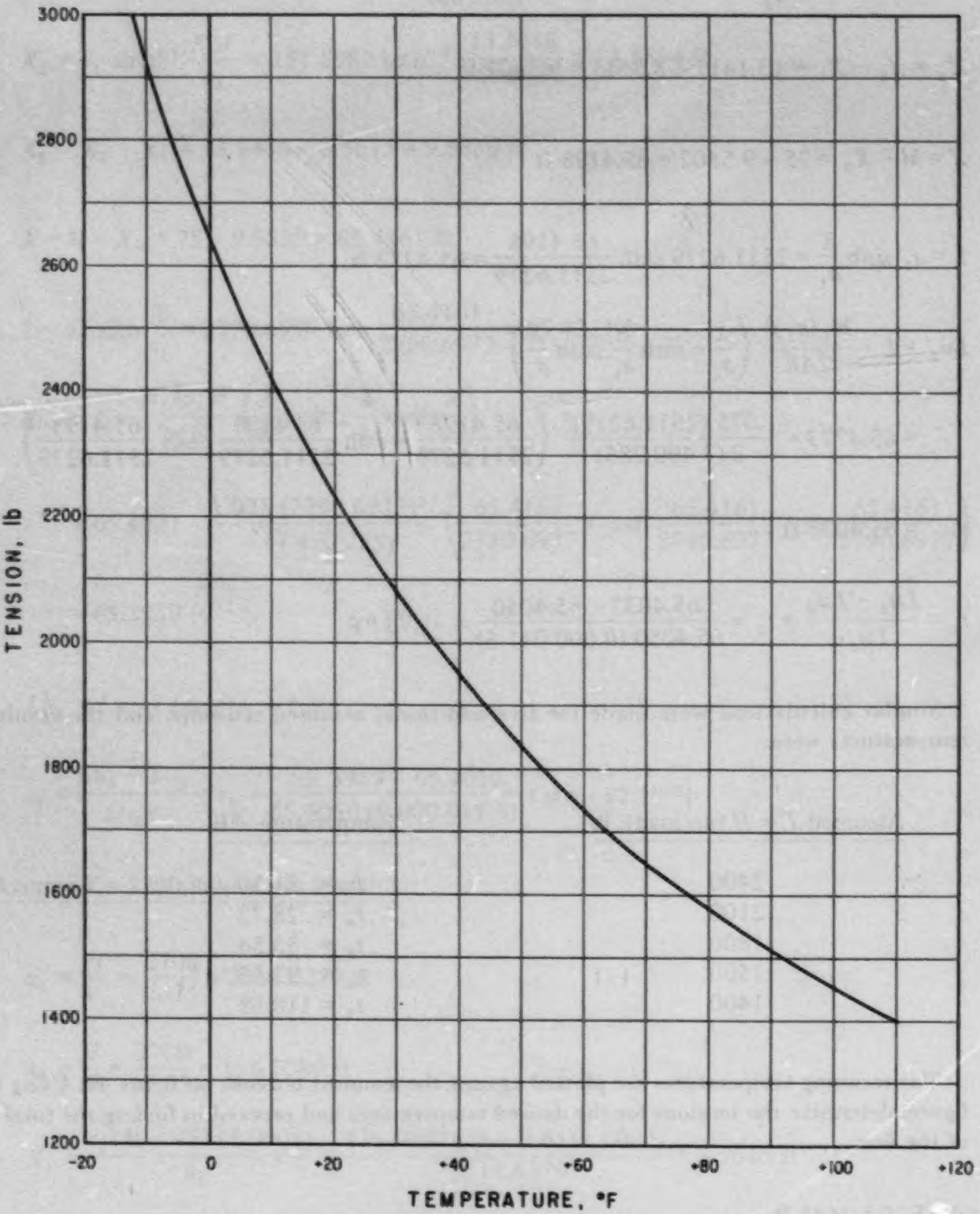


Figure 40.–Tension-temperature curve for insulator effect problem (U.S. customary). 104-D-1068.

$$a_2 = \frac{H}{W} = \frac{2645}{19.75} = 133.9241 \text{ ft}$$

$$X_1 = \frac{a_2 (M - RS)(1.0005)}{a_1} = \frac{133.9241\,(75 - 9.60)\,(1.0005)}{2460.4651} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 133.9241 \sinh \frac{3.5615}{133.9241} = 3.5619 \text{ ft}$$

$$RSP = RS + SP = 9.6 + 3.5619 = 13.1619 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 133.9241 \sinh^{-1} \frac{13.1619}{133.9241} = 13.1408 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.1408 - 3.5615 = 9.5793 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5793 = 65.4207 \text{ ft}$$

$$D_1 = a_2 \left(\cosh \frac{X_1}{a_2} - 1\right) = 133.9241 \left(\cosh \frac{3.5615}{133.9241} - 1\right) = 0.0474 \text{ ft}$$

$$D_2 = a_2 \left(\cosh \frac{X_2}{a_2} - 1\right) = 133.9241 \left(\cosh \frac{13.1408}{133.9241} - 1\right) = 0.6452 \text{ ft}$$

$$D_3 = a_1 \left(\cosh \frac{X}{a_1} - 1\right) = 2460.4651 \left(\cosh \frac{65.4207}{2460.4651} - 1\right) = 0.8698 \text{ ft}$$

$$D_4 = D_3 + D_2 - D_1 = 0.8698 + 0.6452 - 0.0474 = 1.4676 \text{ ft}$$

At 30 °F, T = 2075 lb

$$a_1 = \frac{H}{W_1} = \frac{2075}{1.075} = 1930.2326 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{2075}{19.75} = 105.0633 \text{ ft}$$

$$X_1 = \frac{a_2 (M - RS)(1.0005)}{a_1} = \frac{105.0633\,(75 - 9.60)\,(1.0005)}{1930.2326} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 105.0633 \sinh \frac{3.5615}{105.0633} = 3.5622 \text{ ft}$$

$$RSP = RS + SP = 9.60 + 3.5622 = 13.1622 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1}\frac{RSP}{a_2} = 105.0633 \sinh^{-1} \frac{13.1622}{105.0633} = 13.1280 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.1280 - 3.5615 = 9.5665 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5665 = 65.4335 \text{ ft}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 105.0633\left(\cosh \frac{3.5615}{105.0633} - 1\right) = 0.0604 \text{ ft}$$

$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 105.0633\left(\cosh \frac{13.1280}{105.0633} - 1\right) = 0.8213 \text{ ft}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 1930.2326\left(\cosh \frac{65.4335}{1930.2326} - 1\right) = 1.1092 \text{ ft}$$

$$D_4 = D_3 + D_2 - D_1 = 1.1092 + 0.8213 - 0.0604 = 1.8701 \text{ ft}$$

At 60 °F, $T = 1733$ lb

$$a_1 = \frac{H}{W_1} = \frac{1733}{1.075} = 1612.0930 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{1733}{19.75} = 87.7468 \text{ ft}$$

$$X_1 = \frac{a_2 (M - RS)(1.0005)}{a_1} = \frac{87.7468\,(75 - 9.60)\,(1.0005)}{1612.0930} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 87.7468 \sinh \frac{3.5615}{87.7468} = 3.5625 \text{ ft}$$

$$RSP = RS + SP = 9.60 + 3.5625 = 13.1625 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 87.7468 \sinh^{-1} \frac{13.1625}{87.7468} = 13.1136 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.1136 - 3.5615 = 9.5521 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5521 = 65.4479 \text{ ft}$$

$$D_1 = a_2 \left(\cosh \frac{X_1}{a_2} - 1 \right) = 87.7468 \left(\cosh \frac{3.5615}{87.7468} - 1 \right) = 0.0723 \text{ ft}$$

$$D_2 = a_2 \left(\cosh \frac{X_2}{a_2} - 1 \right) = 87.7468 \left(\cosh \frac{13.1136}{87.7468} - 1 \right) = 0.9817 \text{ ft}$$

$$D_3 = a_1 \left(\cosh \frac{X}{a_1} - 1 \right) = 1612.0930 \left(\cosh \frac{65.4479}{1612.0930} - 1 \right) = 1.3287 \text{ ft}$$

$$D_4 = D_3 + D_2 - D_1 = 1.3287 + 0.9817 - 0.0723 = 2.2381 \text{ ft}$$

At 90 °F, $T = 1513$ lb

$$a_1 = \frac{H}{W_1} = \frac{1513}{1.075} = 1407.4419 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{1513}{19.75} = 76.6076 \text{ ft}$$

$$X_1 = \frac{a_2 (M - RS)(1.0005)}{a_1} = \frac{76.6076\,(75 - 9.60)(1.0005)}{1407.4419} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh \frac{X_1}{a_2} = 76.6076 \sinh \frac{3.5615}{76.6076} = 3.5628 \text{ ft}$$

$$RSP = RS + SP = 9.60 + 3.5628 = 13.1628 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1} \frac{RSP}{a_2} = 76.6076 \sinh^{-1} \frac{13.1628}{76.6076} = 13.0989 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.0989 - 3.5615 = 9.5374 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5374 = 65.4626 \text{ ft}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 76.6076\left(\cosh\frac{3.5615}{76.6076} - 1\right) = 0.0828 \text{ ft}$$

$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 76.6076\left(\cosh\frac{13.0989}{76.6076} - 1\right) = 1.1306 \text{ ft}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 1407.4419\left(\cosh\frac{65.4626}{1407.4419} - 1\right) = 1.5227 \text{ ft}$$

$$D_4 = D_3 + D_2 - D_1 = 1.5227 + 1.1306 - 0.0828 = 2.5705 \text{ ft}$$

At 110 °F, $T = 1405$ lb

$$a_1 = \frac{H}{W_1} = \frac{1405}{1.075} = 1306.9767 \text{ ft}$$

$$a_2 = \frac{H}{W} = \frac{1405}{19.75} = 71.1392 \text{ ft}$$

$$X_1 = \frac{a_2\,(M - RS)\,(1.0005)}{a_1} = \frac{71.1392\,(75 - 9.60)\,(1.0005)}{1306.9767} = 3.5615 \text{ ft}$$

$$SP = a_2 \sinh\frac{X_1}{a_2} = 71.1392 \sinh\frac{3.5615}{71.1392} = 3.5630 \text{ ft}$$

$$RSP = RS + SP = 9.60 + 3.5630 = 13.1630 \text{ ft}$$

$$X_2 = a_2 \sinh^{-1}\frac{RSP}{a_2} = 71.1392 \sinh^{-1}\frac{13.1630}{71.1392} = 13.0890 \text{ ft}$$

$$X_3 = X_2 - X_1 = 13.0890 - 3.5615 = 9.5275 \text{ ft}$$

$$X = M - X_3 = 75 - 9.5275 = 65.4725 \text{ ft}$$

$$D_1 = a_2\left(\cosh\frac{X_1}{a_2} - 1\right) = 71.1392\left(\cosh\frac{3.5615}{71.1392} - 1\right) = 0.0892 \text{ ft}$$

$$D_2 = a_2\left(\cosh\frac{X_2}{a_2} - 1\right) = 71.1392\left(\cosh\frac{13.0890}{71.1392} - 1\right) = 1.2075 \text{ ft}$$

$$D_3 = a_1\left(\cosh\frac{X}{a_1} - 1\right) = 1306.9767\left(\cosh\frac{65.4725}{1306.9767} - 1\right) = 1.6403 \text{ ft}$$

$$D_4 = D_3 + D_2 - D_1 = 1.6403 + 1.2075 - 0.0892 = 2.7586 \text{ ft}$$

18. Spans With Concentrated Loads.–Problems relating to spans with concentrated loads are infrequent and are confined mainly to substation or switchyard spans in which taps or tie-down arrangements are used. Such problems are complicated by the elastic effects of the tap or tie-down in addition to the dead force applied. A method which adequately treats this problem is shown on figure 41.

Probably a better approach to this problem than the method shown on figure 41 would be to sag the conductors to the calculated normal sag for a given temperature and then add a calculated length of conductor to the span to compensate for the force of the tie-down, see figure 42. The required additional length of conductor may be determined by the following procedure which was developed by a former Bureau engineer, F. F. Priest:

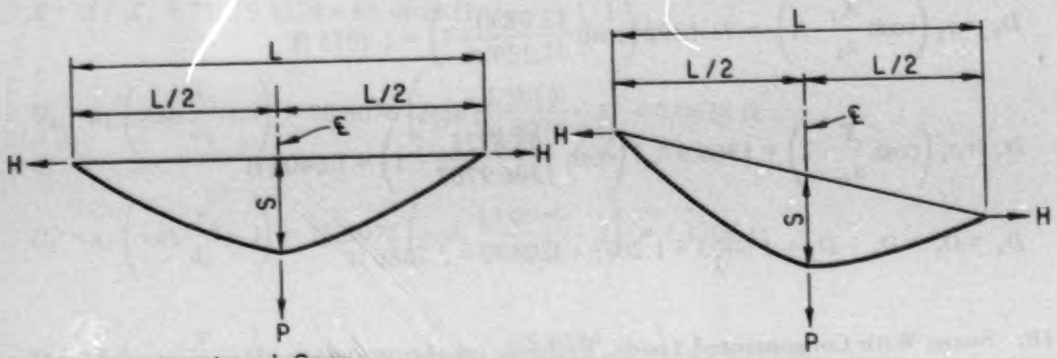
1. Assume a desired spring tension at some given temperature.
2. Calculate the angle that will be formed by a vertical line and the position of the insulator string that will result from the horizontal tension in the conductor and the vertical force due to the tie-down after installation ($\theta = \tan^{-1} H/P$).
3. By multiplying the length of the insulator string by the sine of this angle, the horizontal reflected length of the insulator string is obtained ($i_H = i \sin \theta$).

The difference between the length of the insulator string as it will lay in the near horizontal position in the originally sagged span and its calculated horizontal reflected length after the tie-down is made, indicates the additional amount of conductor required to give the final tied-down span about the same characteristics as the originally sagged span without the tie-down.

Example

Conductor: 242 mm^2 (477 kcmil), ASCR 24/7
Span length = 45.7 m (150 ft)
Force of hardware on tie-down = 444.8 N (100 lb)
Spring tension at 15.5 °C (60 °F) = 889.6 N (200 lb)
Length of insulator string = 1829 mm (6 ft)

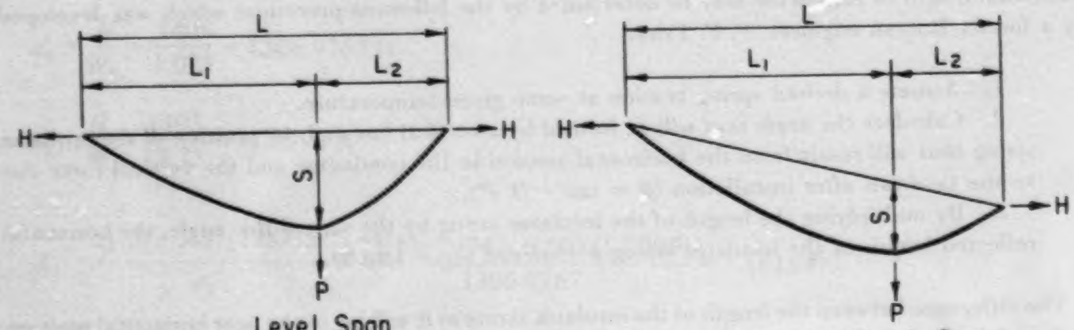
Calculate sags and tensions for the conductor, without tie-down, for a range of temperatures that might be applicable during installation. If the insulator force will be appreciable in a comparatively short span, such as in the example used here, the original sags should be determined by considering the insulator effect (see sec. 16).



Level Span Inclined Span

$$S = \frac{2PL + wL^2}{8H}$$

CONCENTRATED LOAD AT CENTER OF SPAN



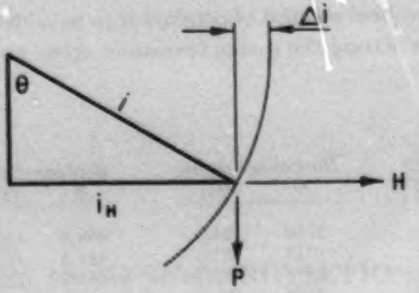
Level Span Inclined Span

$$S = \frac{L_1 L_2 (2P + wL)}{2LH}$$

LOAD AT ANY POINT ON SPAN

L = Horizontal span length between conductor support points, m (ft)
H = Horizontal tension in conductor, N (lb)
S = Sag, from line of supports at concentrated load, m (ft)
P = Concentrated load, N (lb)
w = Linear force factor (weight) of conductor, N/m (lb/ft)
L_1, L_2 = Horizontal distance from concentrated load to points of support, m (ft)

Figure 41.–Spans with concentrated loads. 104-D-1069.



i - Length of insulator string, mm (ft)
i_H - Horizontal reflected length of insulator string, mm (ft)
Δi - $i - i_H$, mm (ft)
H - Horizontal tension in conductor, N (lb)
P - Vertical force added by tie-down (hardware + spring tension), N (lb)

Figure 42.–Graphical method for determining additional length of conductor required for concentrated load problem. 104-D-1070.

Assume the following sag and tension values have been obtained by previous calculations:

Temperature, °C	(°F)	*Sag,* mm	(ft)	*Tension,* N	(lb)
-18	(0)	625	(2.05)	3750	(843)
-1	(30)	780	(2.56)	3015	(678)
15.5	(60)	917	(3.01)	2571	(578)
32	(90)	1039	(3.41)	2268	(510)
49	(120)	1149	(3.77)	2050	(461)

For 15.5 °C:

$\theta = \tan^{-1} 2571/1334.4$

$= \tan^{-1} 1.926\,70$

$= 62.57^\circ$

$i_h = 1829 \sin\theta = 1829\ (0.887\,57)$

$= 1623.37$ mm

$\Delta i = 1829 - 1623.37 = 205.63$ mm

For 60 °F:

$\theta = \tan^{-1} 578/300$

$= \tan^{-1} 1.926\,70$

$= 62.57^\circ$

$i_h = 6 \sin\theta = 6\ (0.887\,57)$

$= 5.33$ ft

$\Delta i = 6 - 5.33 = 0.67$ ft $= 8$ in

The Δi value is the additional amount of conductor to be added to the span after the initial sagging. Considering θ constant for setting the spring tension at other temperatures, the following tabulation can be made:

Temperature,		*Horizontal tension,*		*Hardware force,*		*Spring tension,*	
°C	(°F)	N	(lb)	N	(lb)	N	(lb)
−18	(0)	3750	(843)	444.8	(100)	1501	(337.5)
−1	(30)	3015	(678)	444.8	(100)	1120	(251.9)
15.5	(60)	2571	(578)	444.8	(100)	890	(200)
32	(90)	2269	(510)	444.8	(100)	733	(164.7)
49	(120)	2050	(461)	444.8	(100)	620	(139.3)

« Chapter III

INSULATION, LIGHTNING PROTECTION, AND CLEARANCE PATTERNS

19. Insulation Coordination.–Insulation coordination is the selection of an insulation structure which will withstand the voltage stresses to which the system or equipment will be subjected. There are three different voltage stresses to consider when determining insulation and electrical clearance requirements for the design of high-voltage transmission lines:

(1) Lightning voltages,
(2) Switching voltages, and
(3) 60-Hz voltages, called power frequency operating voltages.

The probability of flashover must be controlled so that any system disturbance is minor.

Lightning impulse voltages generally have the highest values and the highest rates of voltage rise. The time range for these voltages to crest is about 0.5 to 6 microseconds. Although it is impractical to provide a sufficiently high impulse insulation level to withstand the voltage developed when a conductor is struck by an average strength lightning stroke, lightning flashovers may be controlled. This is done by locating overhead ground wires to intercept direct strokes and divert the lightning current to earth through the steel towers or through the ground wires provided on wood pole structures for this purpose. This diversion of the current is accomplished by coordinating the insulator string and air gap insulation values, and by obtaining a sufficiently low footing resistance.

In a region of average storm intensity of 30 storm days per year, a transmission line will be struck on the average of 100 direct strokes per 161 km (100 mi) of line per year. Overhead ground wires must be used on transmission lines to take these direct lightning strokes and shield the conductors. The lightning current is expected to follow a path along the shield wire, down the tower, and through the tower footing resistance to the ground. The entire top of the tower and the connected overhead ground wire will attain a high voltage, mainly because of the current resistance in the tower footing.

An evaluation of tower clearances and conductor and overhead ground wire configurations for an acceptable lightning protection design is based primarily on theory and experience. The major factors affecting the lightning performance of a transmission line are:

- Isoceraunic level (number of lightning storm days to be expected each year)
- Stroke-current magnitude and wave shape
- Tower height
- Tower footing resistance
- Number and location of overhead ground wires (shield angles to conductors)
- Span length
- Midspan clearance between conductors and overhead ground wires
- Number of insulator units

If the permissible stroke current to midspan is more than twice the permissible stroke current to the tower, strokes to midspan may cause tower flashovers.

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For transmission lines up to 345 kV, line insulation is determined primarily by the lightning flashover rate. At 345 kV, the line insulation may be dictated by either switching surge considerations or by the lightning flashover rate. Above 345 kV, switching surges become the prime factor in flashover considerations and will probably control the insulation design; however, protection against lightning must not be overlooked. The probability of flashover due to a switching surge is a function of the line insulation characteristics and the magnitude of the surges expected. The number of insulators used may be selected to keep the probability of flashover from switching surges very low. Switching surge impulse insulation strength is based on tests that have been made on simulated towers where adjustments could be made to duplicate almost any tower shape. At EHV (extra-high voltage) levels, an increase in insulation length does not result in a proportional increase in switching surge withstand strength. For example, a 10-percent increase in the number of insulators does not result in a 10-percent increase in switching surge strength. This is due to the electric field distortion caused by the proximity of the tower surfaces and is called the *proximity effect*. This effect does not apply to lightning impulses, so switching surge considerations will dictate the insulation values at the EHV levels.

Wave shapes for lightning impulses and switching surges are infinite in number, but have been grouped for testing and to provide basic data for use in insulation. Wave shape is defined by two parameters:

(1) The time to crest, which is the interval between the beginning of the impulse and the instant that the voltage reaches its peak value.

(2) The time to half value, which is defined as the time interval between the beginning of the impulse and the instant, on the tail of the impulse, at which the voltage is one-half of the crest value.

Time to crest is the principal parameter affecting flashovers.

The BIL (basic impulse insulation level) is based on a 1.2- by 50-microsecond wave shape. The 1.2-microsecond time to crest is within the range of a typical lightning surge of 0.5 to 6 microseconds, so lightning impulse stress is usually coordinated with the BIL. Coordination of switching surges, which have a time to crest ranging from 50 to 2000 microseconds, lies somewhere between the BIL and 60-Hz withstand. As EHV and UHV transmission have developed, there has been an increasing amount of outdoor switching surge impulse testing of transmission towers and equipment. These tests have resulted in better data for coordination of line insulation and switching surge voltages.

Two types of switching operations are of concern in transmission line insulation coordination. One is the energizing of a line with no initial voltage; the other is high-speed reclosing following a line tripout. The latter switching operation is similar to energization, but there may be energy trapped on the line from the previous opening. Transformers connected to ground will normally dissipate the trapped energy charge in the high-speed reclosing period, and reclosing becomes the same as energization. The switching surge voltage varies with breaker characteristics, line length, and the state of the system at the time of switching.

Restriking occurs when lines are being deenergized and the recovery voltage across the circuit breaker builds up at a faster rate than the dielectric strength of the interrupting medium. This results in momentary reestablishment of the arc across the interrupting contacts and can produce extreme voltages on the system.

Resistors are incorporated in the closing stroke of a breaker to help reduce switching surge overvoltages for EHV lines which, in turn, helps reduce the switching surge requirements for line insulation.

Some causes of switching surge overvoltages are:

- Normal line energizing and deenergizing
- High-speed line reclosing
- Switching capacitor banks, shunt reactors, and cable circuits
- Load rejection
- Out-of-phase switching
- Reinsertion of series capacitors
- Circuit breaker restriking
- Current chopping

Power frequency overvoltages are caused by an abnormal condition which exists until a change in the system alters or removes the condition, such as:

- Voltages on the unfaulted phases during a phase-to-ground fault
- Load rejection
- Open end of a long energized line (Ferranti effect)
- Ferroresonance

Although the clearance necessary for power frequency voltage is much less than for switching surges or lightning, the clearance envelope is very sensitive to the insulator swing angle created by the wind. Data on extreme winds during storms and their frequency of occurrence are necessary to determine power frequency electrical insulation clearances.

In transmission line design, there are two basic insulations to be considered, the insulator string and air. The insulator swing angle depends on the diameter-to-force (weight) ratio of the conductor, and the ratio of wind span to low-point span.

Consideration must be given to each of the three types of voltage stress: (1) lightning impulse, (2) switching surge, and (3) power frequency. Switching surge performance is based on the probability of flashover following a circuit breaker operation. Lightning performance is measured by the number of tripouts per 161 km (100 mi) of line per year. Power frequency performance is measured in terms of the mean recurrence interval.

Bureau wood-pole designs are based on coordination of the impulse insulation value of the insulators with the minimum air gap between the conductor and the structure with a wind pressure of 0.19 kPa (4 lb/ft^2) at 15.5 °C (60 °F). On steel structures, the impulse insulation and the air-gap clearance to the structure are coordinated for the sideswing angle of the suspension insulator strings caused by a 0.19-kPa wind pressure at 15.5 °C on the conductors, or for a sideswing angle of 30°, whichever is greater. For complete coordination, the clearance at midspan between the overhead ground wires and the conductor must be made sufficient so that flashover between the overhead ground wires and the conductors will not occur before flashover occurs at the structure. The separation at midspan must be greater than at the structure because of the impedance of the overhead ground wires. See section 20 for minimum midspan clearances.

Insulation withstand must be coordinated across the insulator string and the air gap. Factors included in an evaluation of the insulation withstand of an insulator string are:

- Maximum system operating voltage
- Crest factor of wave
- Maximum switching surge overvoltage
- Strength of air to switching surges in relation to the impulse strength of the insulators, or the ratio of critical impulse to switching surge withstand
- Percent allowance made between withstand voltage and critical flashover of air, or ratio of withstand to critical flashover

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- Contaminated atmosphere (chemicals, etc.)
- Nonstandard air density (altitude)
- Maximum fault voltage on unfaulted phases
- Factor of safety

The maximum operating voltage can vary, but a 5-percent overvoltage is generally accepted for this limit. The crest factor of the wave is $\sqrt{2}$.

The maximum switching surge varies with breaker characteristics, line length, and the state of the system at the time of switching. The variation in the switching surges can be described by statistical distribution; that is, taking the surge magnitude values for all switching situations and weighting these values by their frequency of occurrence. To be more conservative, it is probably satisfactory to use the one or two switching situations that produce the highest surge values. The insulation strengths of insulator strings and air gaps are described by strength distributions determined from test data on a full-scale tower. These distributions will vary depending upon the proximity of grounded surfaces, humidity, and barometric pressure. The Bureau uses 1.175 as the ratio of the impulse strength for air to the switching surges. Some designers like to use a 3-sigma value as a ratio between withstand and the critical flashover, but since sigma is a variable depending upon gap length, wave shape, and gap configuration, we have set 17.5 percent as a coordination value. A factor of 1.1 is used for contaminated atmosphere. An added altitude factor for nonstandard air is dependent upon the elevation of the given transmission line above sea level.

A factor of 1.5 for contaminated atmosphere, 1.2 for the maximum fault voltage on unfaulted phases, and a safety factor of 1.25 are used when examining the insulation strength for power frequency overvoltages.

For 115-kV wood-pole transmission line construction, one extra insulator unit is added to allow for a possible defective unit. For 115-kV steel structures, two extra units are added: for 230-kV steel construction, two extra units are added, one for a possible defective unit and one for hot-line maintenance; and, on 345-kV steel construction, one extra unit is added as a combination safety unit for a defective unit and for hot-line maintenance. These extra units have proven to be very valuable because in addition to the hot-line maintenance safety they afford, they have helped to restrict Bureau transmission lines to minimal "unexplained" flashovers and outages. Such flashovers and outages are not only frustrating, but they are costly to an electrical entity and must be taken into consideration in the original design.

Tables 16, 17, and 18 show examples of insulation selection for three different voltages. These tables show that the permissible elevation limit is governed by the switching surge impulse values. The lower of the two elevation limits shown in the tables should be used for design purposes. The extra insulator units previously discussed for hot-line maintenance and possible defective units, should not be included in the calculations shown in the tables.

If a transmission line is to operate basically problem free, then insulation coordination is a necessity. Some designers, to reduce initial costs of lines or because of lack of facts, have chosen to ignore some factors such as insulation coordination which results in lines that have many unexplained outages. Such design is not economical when considered over a period of time. Insulation coordination is discussed further in section 21.

20. Lightning Protection.–In 1930, C. L. Fortescue, a consulting transmission line engineer with Westinghouse, wrote a series of articles on lightning investigations that were published in *Electrical Journal.* He advanced the theory that high-voltage transmission lines should be protected from direct strokes of lightning. Previous to that time, transmission lines were designed on the basis of

Table 16.–*Insulation selection for 345 kV*

	Switching surge impulse, positive critical	Power frequency, 60-Hz wet
a. Overvoltage	1.05	1.05
b. Crest factor	1.414	
c. Switching surge	2.5	
d. Ratio of critical impulse to switching surge	1.175	
e. Ratio of withstand to critical flashover voltage	1.175	1.175
f. Contaminated atmosphere	1.1	1.5
g. Factor of safety	1.15	1.25
h. Rise due to line faults		1.2
Total withstand multiplying factor (at sea level). Product of (a) through (h)	6.48	2.78
Normal line to neutral, $345/\sqrt{3} = 199.2$ kV		
Total withstand multiplying factor (at sea level) times normal line to neutral voltage	1291 kV	554 kV
Flashover of 18 insulator units, 146 by 267 mm (5-3/4 by 10-1/2 in), from table B-7 in appendix B	1585 kV	690 kV
Factor for nonstandard air density (altitude)	1585/1291 = 1.23	690/554 = 1.25
From table B-10 in appendix B, permissible elevation limit	2154 m (7068 ft)	2362 m (7750 ft)

induced-stroke assumption; namely, that a charge cloud in the vicinity of the transmission line, with its accompanying gradient of voltage to ground, would bind a charge on the line. The discharge of the cloud to any object other than a transmission line, would release this bound charge, which was then free to travel along the line seeking a path to ground. However, induced voltage gradients appearing on transmission lines during nearby lightning discharges have proved to be too low to account for the damage to the lines. The direct-stroke theory is now generally accepted for high-voltage lines. Complete protection against direct strokes requires a shield to prevent lightning from striking the electrical conductors, together with adequate insulation of the structures and adequate drainage facilities so that the discharge can drain to ground without affecting the conductors. The shielding method does not allow the formation of an arc from the line conductor to ground. An alternative nonshielding method of protection by auxiliary devices, such as protector tubes or ground fault neutralizers, does allow an arc to form between the ground structure and the conductors but provides a means for quenching the arc without interrupting the line circuit. The four basic requirements for the design of a line based on the direct-stroke theory are:

(1) Ground wires with sufficient mechanical strength must be locatd to adequately shield the line conductors from direct strokes.

(2) Adequate clearance from the line conductor to the tower or ground must be maintained so that the full effectiveness of the insulating structure can be obtained.

(3) Adequate clearances from overhead ground wires to conductors must be maintained, especially at midspan, to prevent flashover to the conductors for voltages up to the protective voltage level used in the line design.

Table 17.–*Insulation selection for 230 kV*

	Switching surge impulse, positive critical	Power frequency, 60-Hz wet
a. Overvoltage	1.05	1.05
b. Crest factor	1.414	
c. Switching surge	2.5	
d. Ratio of critical impulse to switching surge	1.175	
e. Ratio of withstand to critical flashover voltage	1.175	1.175
f. Contaminated atmosphere	1.1	1.5
g. Factor of safety	1.2	1.25
h. Rise due to line faults		1.2
Total withstand multiplying factor (at sea level). Product of (a) through (h)	6.76	2.78
Normal line to neutral, $230/\sqrt{3} = 132.8$ kV		
Total withstand multiplying factor (at sea level) times normal line to neutral voltage	898 kV	369 kV
Flashover of 12 insulator units, 146 by 254 mm (5-3/4 by 10 in), from table B-7 in appendix B	1105 kV	490 kV
Factor for nonstandard air density (altitude)	1105/898 = 1.23	490/369 = 1.32
From table B-10 in appendix B, permissible elevation limit	2154 m (7068 ft)	3139 m (10 299 ft)

(4) Tower footing impedances as low as economically justified must be obtained.

To meet the first of these requirements, two overhead ground wires are used on all lines using H-frame wood-pole construction and generally on all steel tower lines. For standard construction, overhead ground wires are not normally used on lines of 46 kV or less. On 69-kV lines, overhead ground wires are used for a distance of 0.8 km (0.5 mi) in each direction from the substations or for the entire length of line. On lines of 115 kV and higher, overhead ground wires normally are used for the entire length of the line. On transmission lines for voltages up to and including 161 kV, 10-mm (3/8-in), 7-wire, high-strength galvanized steel strand is used for overhead ground wires. On 230 kV and above lines, 13-mm (1/2-in), 7-wire, high-strength galvanized steel strand overhead ground wires are used. On lines where very heavy ice loading, radial ice thickness of 25 mm (1 in) or more, occurs or for extra long spans, it is desirable to use extra-high-strength steel for the overhead ground wires so that the extra heavy loads may be carried without excessive sag. In areas near a sea coast, where saline fogs occur, and in other areas having a contaminated atmosphere, it is desirable to use a more corrosion resistant material such as Alumoweld for the overhead ground wires. In order to locate the overhead ground wires to shield the conductors adequately, the poles in wood-pole lines should be extended high enough to provide a 30° cone of protection at tangent structures. This means that a straight line drawn through the overhead ground wire and the outside conductor should make a maximum angle of 30° with the vertical. At steel towers, the overhead ground wires should be located to give a maximum angle of protection of 20°. Where the terrain slopes across a transmission line, the angle of protection should be decreased in order to maintain an angle of less than 30° for

Table 18.–*Insulation selection for 115 kV*

	Switching surge impulse, positive critical	Power frequency, 60-Hz wet
a. Overvoltage	1.05	1.05
b. Crest factor	1.414	
c. Switching surge[1]	2.8	
d. Ratio of critical impulse to switching surge	1.175	
e. Ratio of withstand to critical flashover voltage	1.175	1.175
f. Contaminated atmosphere	1.1	1.5
g. Factor of safety	1.2	1.25
h. Rise due to line faults		1.2
Total withstand multiplying factor (at sea level). Product of (a) through (h)	7.57	2.78
Normal line to neutral, $115/\sqrt{3} = 66.4$ kV		
Total withstand multiplying factor (at sea level) times normal line to neutral voltage	503 kV	185 kV
Flashover of 6 insulator units, 146 by 254 mm (5-3/4 by 10 in), from table B-7 in appendix B	610 kV	255 kV
Factor for nonstandard air density (altitude)	610/503 = 1.21	255/185 = 1.38
From table B-10 in appendix B, permissible elevation limit	1946 m (6386 ft)	3864 m (12 676 ft)

[1] A switching surge value of 2.8 is a more realistic value for 115-kV lines than the 2.5 value used for 230- and 345-kV lines.

wood-pole lines, and less than 20° for steel tower lines. These angles would be between a line through the overhead ground wire and the outside conductor, and a line perpendicular to the surface of the earth.

If steel towers exceed 38.1 m (125 ft) in height, the angle or protection should be reduced as indicated on figure 43.

To maintain adequate clearance between the structure and the conductors, the air-gap distance between any conductor and the structure should be sufficient to coordinate the impulse flashover voltages of the air gap and the insulation used on the structures, under the conditions at which lightning is likely to occur. Almost all electrical storms occur at temperatures between minus 1 and 32 °C (30 and 90 °F), and are not likely to occur simultaneously with high winds. Therefore, Bureau designs are based on coordination of the impulse insulation value of the insulators with the minimum air gap between the conductor and the structure with a wind pressure of 0.19 kPa (4 $\mathrm{lb/ft^2}$) at 15.5 °C (60 °F). On wood-pole structures having ground wires running down the pole, the clearance is measured between the conductor and the pole ground wire. On steel structures, the impulse insulation and the air-gap clearance to the structure are coordinated for the sideswing angle of the suspension insulator strings caused by a 0.19-kPa wind pressure on the conductors at 15.5 °C or for a sideswing of 30°, whichever is greater. For complete coordination, the clearance at midspan between the overhead ground wires and the conductors must be made great enough so that flashover between the ground wires and the conductors will not occur before flashover occurs at the structure.

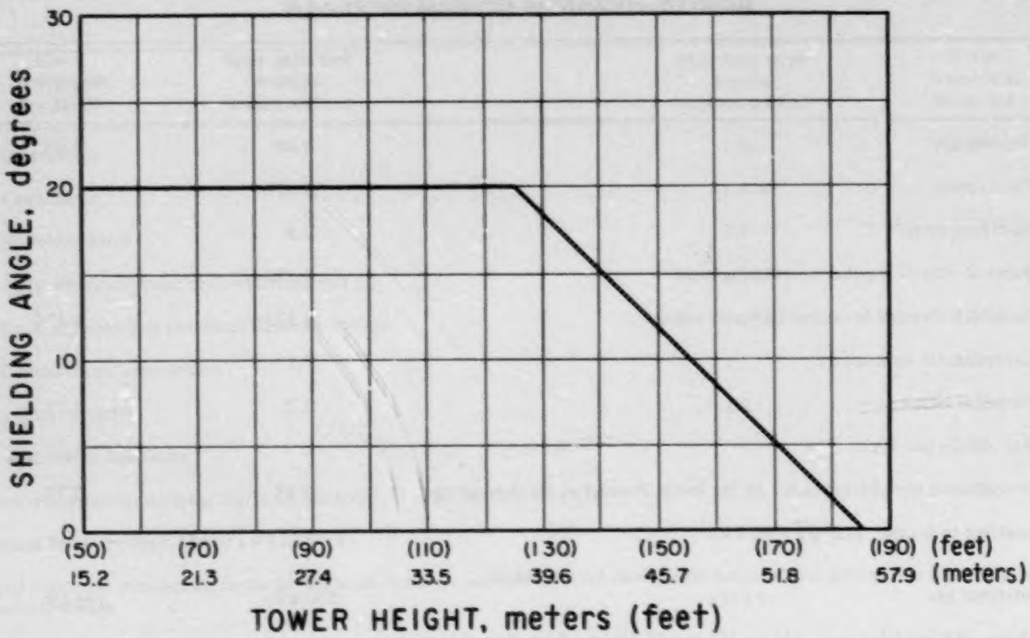

Figure 43.–Reduction of angle of protection against lightning according to structure height. 104-D-1071.

Because of the impedance of the overhead ground wires, the separation at midspan must be greater than at the structure. The amount of separation required depends on the desired protection level, length of span, and the structure footing resistance. Assuming a 15-ohm structure footing resistance and an outage probability of 1 or less per 161 km (100 mi) of line per year, the following tabulation shows the minimum midspan clearances between overhead ground wires and conductors for various span lengths.

Span length, m	(ft)	*Midspan spacing,* m	(ft)
183	(600)	4.6	(15)
213	(700)	6.1	(20)
244	(800)	7.3	(24)
305	(1000)	9.7	(32)
350	(1150)	11.3	(37)
366	(1200)	11.9	(39)
427	(1400)	13.7	(45)
488	(1600)	15.5	(51)
549	(1800)	17.4	(57)

Line voltages have very little relationship to the required midspan clearances, so the preceding tabulation is satisfactory for voltages from 115 to 500 kV. For spans longer than those shown in the tabulation, the sag in the overhead ground wire at 15.5 °C (60 °F) no load, should be equal to about 80 percent of the sag of the conductor at this temperature.

Lightning performance is dependent on the surge resistance of the tower footing, rather than the 60-Hz value usually measured. For footing resistances up to about 15 ohms, the surge resistance is slightly less than the 60-Hz value, but for higher values of resistance, the surge resistance measures considerably less. For footing resistances above 15 ohms, the surge resistance should be estimated, based on the best available data.

All structures in transmission lines having overhead ground wires should be adequately grounded because the effectiveness of these ground wires for lightning protection depends on a low impedance path to ground. Where there are two overhead ground wires, they should be tied together at the top of each structure to reduce the impedance to ground. On wood-pole structures, a ground wire of No. 2 AWG Copperweld wire is connected to the overhead ground wires, carried down the face of the pole, passed under the butt of the pole, and wrapped five complete spiral turns around the butt of the pole. The ground wire is fastened to the pole by means of Copperweld staples. At all 2- and 3-pole structures, an underground connection placed 457 to 610 mm (18 to 24 in) below the ground surface is made between the ground wires on each pole. On steel structures, grounding is usually accomplished through the concrete footings by welding stub angles to reinforcing bars and welding the reinforcing bars to each other. In areas of high resistivity (such as in rocky, mountainous terrain or in sandy, desert areas) a radial counterpoise or a double continuous counterpoise is used when a high level of lightning protection is desired. The two counterpoise wires are placed at least 7.6 m (25 ft) from the centerline of the transmission line, one on each side, and brought into each structure and attached. The counterpoise wires are buried 305 to 457 mm (12 to 18 in) below the earth surface. Figure B-5 in appendix B shows ground resistivity values in ohm-meters for the United States.

An AIEE Committee Report published in 1950 [13][1] was updated and expanded by Clayton and Young in 1964 [14]. The method presented in these reports consists of groups of curves that are based on typical horizontal and vertical conductor and overhead ground wire configurations, a range of span lengths, insulator quantities, and footing resistances. The curves cover a voltage range from 115 to 700 kV. Combinations of insulator quantities and footing resistances for a desired performance can be determined from the curves. When using these curves, use surge resistance values as previously discussed.

For studying the anticipated lightning outages on transmission lines of 345 kV and above, it is suggested that reference [15] be used.

21. Conductor Clearance Patterns.–Before a designer can design steel towers for a transmission line, the following data must be known:

- Type of towers required (single or double circuit)
- Loading area where the line is to be constructed
- Minimum conductor spacing
- Angle of protection (against lightning) that the ground wires must afford the conductors
- Longitudinal, vertical, and transverse loading under full-load conditions for conductors and ground wires at each attachment point
- Maximum line deflection angle
- Ruling span length
- Maximum sum of adjacent spans, and the maximum distance between low points of the adjacent spans
- Insulation coordination

---

[1] Numbers in brackets refer to items in the Bibliography.

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It is the responsibility of the transmission line designer to provide all of the above data. Most of the required data can be calculated or approximated. The angle of protection is discussed in section 20; and insulation coordination, the basis for the construction of conductor clearance patterns, is discussed in section 19.

To maintain adequate clearance between the structure and conductors, the air-gap distance between any conductor and the structure should be sufficient to coordinate the air gap and the structure insulation considering each of the three types of voltage stress (lightning impulse, switching surge, and power frequency) under the condition at which each is likely to govern. The clearances required for the three voltage stresses are, in general, described by the three superimposed patterns indicted on figure 44.

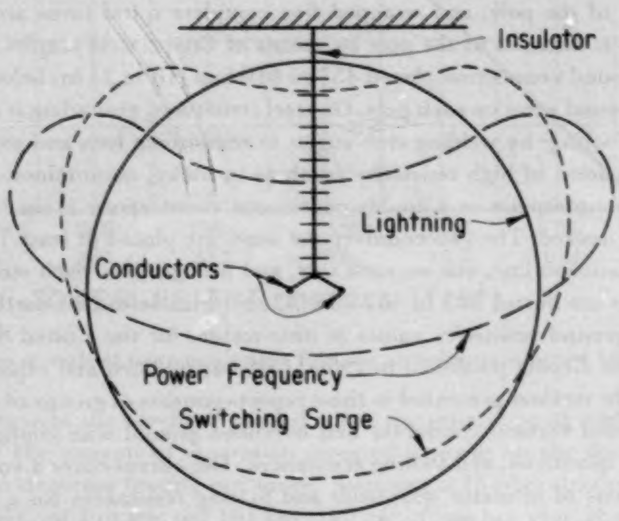


Figure 44.–Superimposed clearance patterns for the three types of voltage stresses. 104-D-1072.

Bureau designs for wood-pole structures are based on coordination of the impulse insulation value of the insulators with the minimum air gap between the conductor and structure, and a wind pressure of 0.19 kPa (4 lb/ft^2) at 15.5 °C (60° F). On steel structures, the impulse insulation of the insulator string and the air-gap clearance to the structure are coordinated for the sideswing angle of the suspension insulator strings caused by a 0.19-kPa wind pressure at 15.5 °C on the conductors or for a sideswing angle of 30°, whichever is greater. In the normal or vertical position of the insulator string, 10 percent is added to the impulse value of the insulator string and an equivalent air gap is used for clearance to the structure. For the power frequency clearance, the maximum wind, usually 0.43 to 0.48 kPa (9 to 10 lb/ft^2), in the area where the line is to be located, is used to define the swing of the insulator string. An air gap equivalent to the wet 60-Hz flashover value of the insulator string is used for the clearance envelope.

An example problem on constructing the clearance patterns follows.

Example Problem

Assume a 345-kV transmission line with:

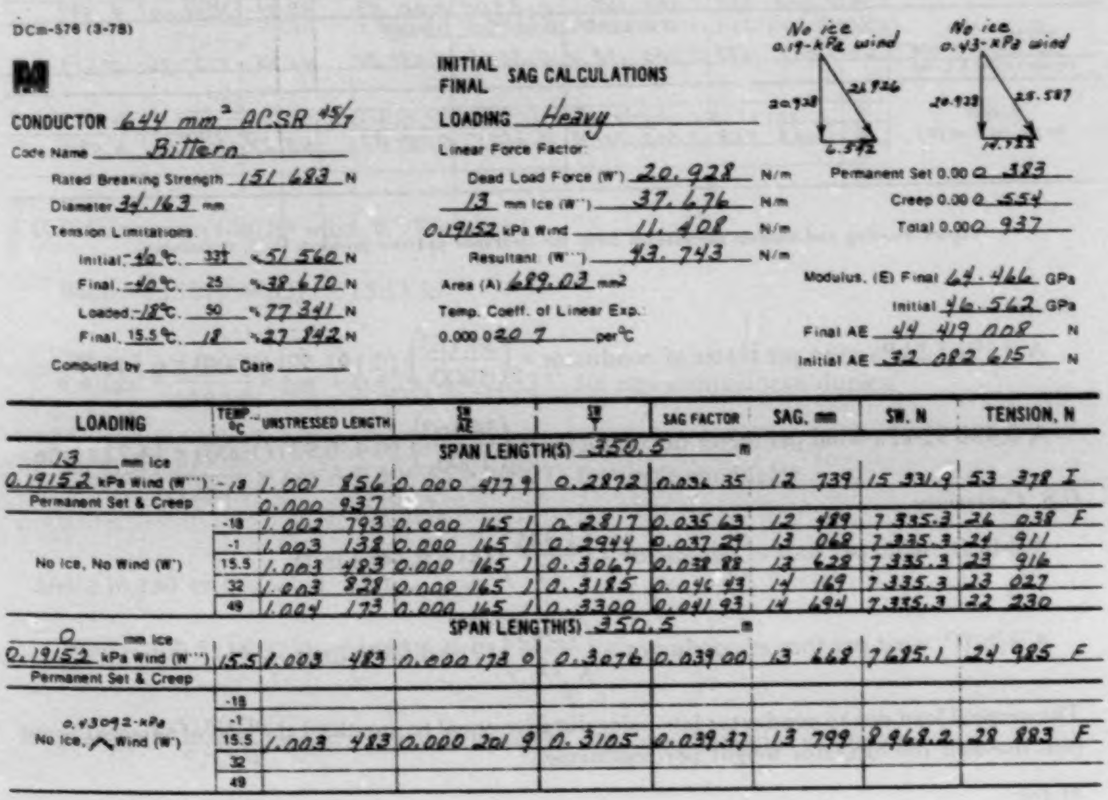
644 mm^2 (1272 kcmil), ACSR, 45/7 duplex conductor. The following data is also assumed:

Maximum initial tension per conductor	= 53 378 N (12 000 lb)
Ruling span	= 350.5 m (1150 ft)
18 insulator units per string	
146 by 267 mm (5-3/4 by 10-1/2 in)	
Length per string	
(single conductor)	= 3099 mm (122 in)
(duplex conductor)	= 3277 mm (129 in)
Vertical force (weight) per string	= 1500.8 N (337.4 lb)
Wind	
Everyday maximum	= 0.19 kPa (4 lb/ft²)
Maximum design	= 0.43 kPa (9 lb/ft²)

Design for a minimum low-point distance equal to one-third the sum of adjacent spans.

Calculations to be made at 15.5 °C (60 °F).

Sag and tension calculations are shown on figures 45 and 46.


No ice
0.19-kPa wind
20.928
21.926
6.392
No ice
0.43-kPa wind
20.928
25.587
14.722

DCm-576 (3-78)

INITIAL
FINAL
SAG CALCULATIONS

CONDUCTOR 644 mm² ACSR 45/7

Code Name Bittern

Rated Breaking Strength 151 683 N

Diameter 34.163 mm

Tension Limitations

Initial -40 °C. 33⅓ % 51 560 N

Final -40 °C. 25 % 38 670 N

Loaded -18 °C. 50 % 77 341 N

Final 15.5 °C. 18 % 27 842 N

Computed by ________ Date ________

LOADING Heavy

Linear Force Factor:

Dead Load Force (W') 20.928 N/m

13 mm Ice (W'') 37.676 N/m

0.19152 kPa Wind 11.408 N/m

Resultant (W''') 43.743 N/m

Area (A) 689.03 mm2

Temp. Coeff. of Linear Exp.

0.000 020 7 per °C

Permanent Set 0.000 383

Creep 0.000 554

Total 0.000 937

Modulus, (E) Final 64.466 GPa

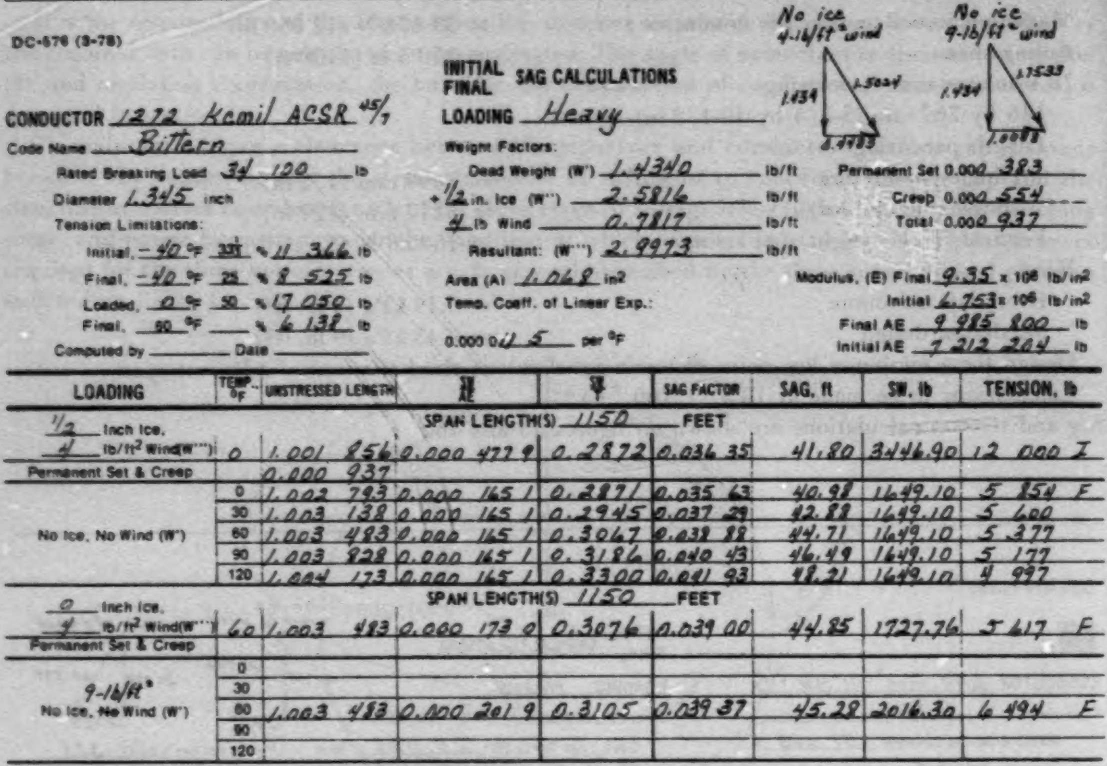
Initial 46.562 GPa

Final AE 44 419 008 N

Initial AE 32 082 615 N

LOADING	TEMP °C	UNSTRESSED LENGTH	SW/AE	SW/T	SAG FACTOR	SAG, mm	SW, N	TENSION, N
			SPAN LENGTH(S) 350.5 m					
13 mm Ice 0.19152 kPa Wind (W''')	-18	1.001 856	0.000 477 9	0.2872	0.036 35	12 739	15 331.9	53 378 I
Permanent Set & Creep		0.000 937						
No Ice, No Wind (W')	-18	1.002 793	0.000 165 1	0.2817	0.035 63	12 489	7 335.3	26 038 F
	-1	1.003 138	0.000 165 1	0.2944	0.037 29	13 068	7 335.3	24 911
	15.5	1.003 483	0.000 165 1	0.3067	0.038 88	13 628	7 335.3	23 916
	32	1.003 828	0.000 165 1	0.3185	0.040 43	14 169	7 335.3	23 027
	49	1.004 173	0.000 165 1	0.3300	0.041 93	14 694	7 335.3	22 230
			SPAN LENGTH(S) 350.5 m					
0 mm Ice 0.19152 kPa Wind (W''')	15.5	1.003 483	0.000 173 0	0.3076	0.039 00	13 668	7 685.1	24 985 F
Permanent Set & Creep								
0.43092-kPa No Ice, Wind (W')	-18							
	-1							
	15.5	1.003 483	0.000 201 9	0.3105	0.039 37	13 799	8 968.2	28 883 F
	32							
	49							

Figure 45.–Sag and tension calculation form for clearance pattern problem (metric).



DC-676 (9-78)

INITIAL / FINAL SAG CALCULATIONS

No ice 4-lb/ft² wind: 1.434, 1.5024, 0.4483

No ice 9-lb/ft² wind: 1.434, 1.7533, 1.0088

CONDUCTOR 1272 kcmil ACSR 45/7

LOADING Heavy

Code Name Bittern

Rated Breaking Load 34 100 lb

Diameter 1.345 inch

Tension Limitations:

Initial, -40 °F 33⅓ % 11 366 lb

Final, -40 °F 25 % 8 525 lb

Loaded, 0 °F 50 % 17 050 lb

Final, 60 °F ___ % 6 138 lb

Computed by ________ Date ________

Weight Factors:

Dead Weight (W') 1.4340 lb/ft

+ 1/2 in. Ice (W'') 2.5816 lb/ft

4 lb Wind 0.7817 lb/ft

Resultant: (W''') 2.9973 lb/ft

Area (A) 1.068 in2

Temp. Coeff. of Linear Exp.:

0.000 0115 per °F

Permanent Set 0.000 383

Creep 0.000 554

Total 0.000 937

Modulus, (E) Final 9.35 x 10⁶ lb/in2

Initial 6.753 x 10⁶ lb/in2

Final AE 9 985 800 lb

Initial AE 7 212 204 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
			SPAN LENGTH(S) 1150 FEET					
1/2 Inch Ice, 4 lb/ft² Wind(W''')	0	1.001 856	0.000 477 9	0.2872	0.036 35	41.80	3446.90	12 000 I
Permanent Set & Creep		0.000 937						
No Ice, No Wind (W')	0	1.002 793	0.000 165 1	0.2871	0.035 63	40.98	1649.10	5 854 F
	30	1.003 138	0.000 165 1	0.2945	0.037 29	42.88	1649.10	5 600
	60	1.003 483	0.000 165 1	0.3047	0.038 88	44.71	1649.10	5 377
	90	1.003 828	0.000 165 1	0.3186	0.040 43	46.49	1649.10	5 177
	120	1.004 173	0.000 165 1	0.3300	0.041 93	48.21	1649.10	4 997
			SPAN LENGTH(S) 1150 FEET					
0 Inch Ice, 4 lb/ft² Wind(W''')	60	1.003 483	0.000 173 0	0.3076	0.039 00	44.85	1727.76	5 617 F
Permanent Set & Creep								
9-lb/ft² No Ice, ~~No~~ Wind (W')	0							
	30							
	60	1.003 483	0.000 201 9	0.3105	0.039 37	45.28	2016.30	6 494 F
	90							
	120							

Figure 46.–Sag and tension calculation form for clearance pattern problem (U.S. customary).

Metric

$$\text{A 0.191 52-kPa wind per meter of conductor} = \left(\frac{34.163}{1000}\right)(0.191\ 52)(1000) = 6.542\ \text{N/m}$$

$$\text{A 0.430 92-kPa wind per meter of conductor} = \left(\frac{34.163}{1000}\right)(0.430\ 92)(1000) = 14.722\ \text{N/m}$$

U.S. Customary

$$\text{A 4-lb/ft}^2 \text{ wind per foot of conductor} = \left(\frac{1.345}{12}\right)(4) = 0.4483\ \text{lb/ft}$$

$$\text{A 9-lb/ft}^2 \text{ wind per foot of conductor} = \left(\frac{1.345}{12}\right)(9) = 1.0088\ \text{lb/ft}$$

The vertical load due to conductor low-point distance equal to one-third the sum of adjacent spans plus one-half the insulator weight per conductor:

Metric

For duplex conductor line: $\frac{(350.5)(2)}{3}(20.928) + \frac{1500.8}{4} = 4890.2 + 375.2 = 5265.4\ \text{N}$

For single conductor line: $\frac{(350.5)(2)}{3}(20.928) + \frac{1500.8}{2} = 4890.2 + 750.4 = 5640.6$ N

U.S. Customary

For duplex conductor line: $\frac{(1150)(2)}{3}(1.434) + \frac{337.4}{4} = 1099.4 + 84.3 = 1183.7$ lb

For single conductor line: $\frac{(1150)(2)}{3}(1.434) + \frac{337.4}{2} = 1099.4 + 168.7 = 1268.1$ lb

Compute θ (angle of insulator swing) for the following conditions:

Metric **(0.191 52-kPa wind, 0° line angle)**

Wind = 350.5 (6.542) = 2293 N

$\theta = \tan^{-1}\frac{2293}{5265.4} = \tan^{-1} 0.435\,48 = 23°32'$, for one conductor of duplex

$\theta = \tan^{-1}\frac{2293}{5640.6} = \tan^{-1} 0.406\,52 = 22°07'$, for single conductor

U.S. Customary **(4-lb/ft² wind, 0° line angle)**

Wind = 1150 (0.4483) = 515.55 lb

$\theta = \tan^{-1}\frac{515.55}{1183.7} = \tan^{-1} 0.435\,54 = 23°32'$, for one conductor of duplex

$\theta = \tan^{-1}\frac{515.55}{1268.1} = \tan^{-1} 0.406\,55 = 22°07'$, for single conductor

Metric **(0.430 92-kPa wind, 0° line angle)**

Wind = 350.5 (14.722) = 5160.06 N

$\theta = \tan^{-1}\frac{5160.06}{5265.4} = \tan^{-1} 0.979\,99 = 44°25'$, for one conductor of duplex

$\theta = \tan^{-1}\frac{5160.06}{5640.6} = \tan^{-1} 0.914\,81 = 42°27'$, for single conductor

U.S. Customary **(9-lb/ft^2 wind, 0° line angle)**

Wind = 1150 (1.0088) = 1160.12 lb

$$\theta = \tan^{-1} \frac{1160.12}{1183.7} = \tan^{-1} 0.980\,08 = 44°25', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{1160.12}{1268.1} = \tan^{-1} 0.914\,85 = 42°27', \text{ for single conductor}$$

Metric **(No wind, 5° line angle)**

$$2T \sin 2.5° = 2\,(23\,916)\,(0.043\,62) = 2086.43$$

$$\theta = \tan^{-1} \frac{2086.43}{5265.4} = \tan^{-1} 0.396\,25 = 21°37', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{2086.43}{5640.6} = \tan^{-1} 0.369\,90 = 20°18', \text{ for single conductor}$$

U.S. Customary **(No wind, 5° line angle)**

$$2T \sin 2.5° = 2\,(5377)\,(0.043\,62) = 469.09$$

$$\theta = \tan^{-1} \frac{469.09}{1183.7} = \tan^{-1} 0.396\,29 = 21°37', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{469.09}{1268.1} = \tan^{-1} 0.369\,91 = 20°18', \text{ for single conductor}$$

Metric **(0.191 52-kPa wind, 5° line angle)**

$$2T \sin 2.5° = 2\,(24\,985)\,(0.043\,62) = 2179.69$$

$$\theta = \tan^{-1} \frac{2179.69 + 2293}{5265.4} = \tan^{-1} 0.849\,45 = 40°20', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{2179.69 + 2293}{5640.6} = \tan^{-1} 0.792\,95 = 38°24', \text{ for single conductor}$$

U.S. Customary **(4-lb/ft² wind, 5° line angle)**

$$2T \sin 2.5^\circ = 2\,(5617)\,(0.043\,62) = 490.03$$

$$\theta = \tan^{-1} \frac{490.03 + 515.55}{1183.7} = \tan^{-1} 0.849\,52 = 40^\circ 20', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{490.03 + 515.55}{1268.1} = \tan^{-1} 0.792\,98 = 38^\circ 24', \text{ for single conductor}$$

Metric **(0.430 92-kPa wind, 5° line angle)**

$$2T \sin 2.5^\circ = 2\,(28\,883)\,(0.043\,62) = 2519.75$$

$$\theta = \tan^{-1} \frac{2519.75 + 5160.06}{5265.4} = \tan^{-1} 1.4585 = 55^\circ 34', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{2519.75 + 5160.06}{5640.6} = \tan^{-1} 1.3615 = 53^\circ 42', \text{ for single conductor}$$

U.S. Customary **(9-lb/ft² wind, 5° line angle)**

$$2T \sin 2.5^\circ = 2\,(6494)\,(0.043\,62) = 566.54$$

$$\theta = \tan^{-1} \frac{566.54 + 1160.12}{1183.7} = \tan^{-1} 1.4587 = 55^\circ 34', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{566.54 + 1160.12}{1268.1} = \tan^{-1} 1.3616 = 53^\circ 42', \text{ for single conductor}$$

Metric **(No wind, 15° line angle)**

$$2T \sin 7.5^\circ = 2\,(23\,916)\,(0.130\,53) = 6243.51$$

$$\theta = \tan^{-1} \frac{6243.51}{5265.4} = \tan^{-1} 1.1858 = 49^\circ 51', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{6243.51}{5640.6} = \tan^{-1} 1.1069 = 47^\circ 54', \text{ for single conductor}$$

U.S. Customary **(No wind, 15° line angle)**

$$2T \sin 7.5° = 2\,(5377)\,(0.130\ 53) = 1403.72$$

$$\theta = \tan^{-1} \frac{1403.72}{1183.7} = \tan^{-1} 1.1858 = 49°51', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{1403.72}{1268.1} = \tan^{-1} 1.1069 = 47°54', \text{ for single conductor}$$

Metric **(0.191 52-kPa wind, 15° line angle)**

$$2T \sin 7.5° = 2\,(24\ 985)\,(0.130\ 53) = 6522.58$$

$$\theta = \tan^{-1} \frac{6522.58 + 2293}{5265.4} = \tan^{-1} 1.6742 = 59°09', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{6522.58 + 2293}{5640.6} = \tan^{-1} 1.5629 = 57°23', \text{ for single conductor}$$

U.S. Customary **(4-lb/ft^2 wind, 15° line angle)**

$$2T \sin 7.5° = 2\,(5617)\,(0.130\ 53) = 1466.37$$

$$\theta = \tan^{-1} \frac{1466.37 + 515.55}{1183.7} = \tan^{-1} 1.6743 = 59°09', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{1466.37 + 515.55}{1268.1} = \tan^{-1} 1.5629 = 57°23', \text{ for single conductor}$$

Metric **(0.430 92-kPa wind, 15° line angle)**

$$2T \sin 7.5° = 2\,(28\ 883)\,(0.130\ 53) = 7540.20$$

$$\theta = \tan^{-1} \frac{7540.20 + 5160.06}{5265.4} = \tan^{-1} 2.4119 = 67°29', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{7540.20 + 5160.06}{5640.6} = \tan^{-1} 2.2516 = 66°03', \text{ for single conductor}$$

U.S. Customary **(9-lb/ft² wind, 15° line angle)**

$$2T \sin 7.5° = 2\,(6494)\,(0.130\ 53) = 1695.32$$

$$\theta = \tan^{-1} \frac{1695.32 + 1160.12}{1183.7} = \tan^{-1} 2.4123 = 67°29', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{1695.32 + 1160.12}{1268.1} = \tan^{-1} 2.2517 = 66°03', \text{ for single conductor}$$

Metric **(-0.191 52-kPa wind, 5° line angle)**

$$\theta = \tan^{-1} \frac{2179.69 - 2293}{5265.4} = \tan^{-1} -0.021\ 52 = -1°14', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{2179.69 - 2293}{5640.6} = \tan^{-1} -0.020\ 09 = -1°09', \text{ for single conductor}$$

U.S. Customary **(-4-lb/ft² wind, 5° line angle)**

$$\theta = \tan^{-1} \frac{490.03 - 515.55}{1183.7} = \tan^{-1} -0.021\ 56 = -1°14', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{490.03 - 515.55}{1268.1} = \tan^{-1} -0.020\ 12 = -1°09', \text{ for single conductor}$$

Metric **(-0.430 92-kPa wind, 5° line angle)**

$$\theta = \tan^{-1} \frac{2519.75 - 5160.06}{5265.4} = \tan^{-1} -0.501\ 44 = -26°38', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{2519.75 - 5160.06}{5640.6} = \tan^{-1} -0.468\ 09 = -25°05\ , \text{ for single conductor}$$

U.S. Customary **(-9-lb/ft² wind, 5° line angle)**

$$\theta = \tan^{-1} \frac{566.54 - 1160.12}{1183.7} = \tan^{-1} -0.501\ 46 = -26°38', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{566.54 - 1160.12}{1268.1} = \tan^{-1} -0.468\ 09 = -25°05', \text{ for single conductor}$$

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Metric **(–0.191 52-kPa wind, 15° line angle)**

$$\theta = \tan^{-1} \frac{6522.58 - 2293}{5265.4} = \tan^{-1} 0.803\ 28 = 38^\circ 46', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{6522.58 - 2293}{5640.6} = \tan^{-1} 0.749\ 84 = 36^\circ 51', \text{ for single conductor}$$

U.S. Customary **(–4-lb/ft² wind, 15° line angle)**

$$\theta = \tan^{-1} \frac{1466.37 - 515.55}{1183.7} = \tan^{-1} 0.803\ 26 = 38^\circ 46', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{1466.37 - 515.55}{1268.1} = \tan^{-1} 0.749\ 80 = 36^\circ 51', \text{ for single conductor}$$

Metric **(–0.430 92-kPa wind, 15° line angle)**

$$\theta = \tan^{-1} \frac{7540.20 - 5160.06}{5265.4} = \tan^{-1} 0.452\ 03 = 24^\circ 19', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{7540.20 - 5160.06}{5640.6} = \tan^{-1} 0.421\ 97 = 22^\circ 52', \text{ for single conductor}$$

U.S. Customary **(–9-lb/ft² wind, 15° line angle)**

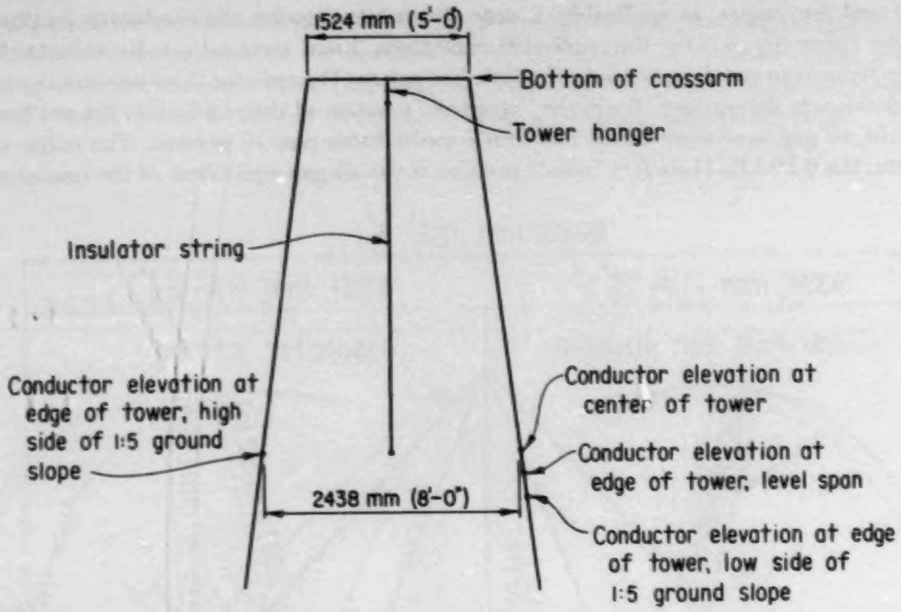
$$\theta = \tan^{-1} \frac{1695.32 - 1160.12}{1183.7} = \tan^{-1} 0.452\ 14 = 24^\circ 19', \text{ for one conductor of duplex}$$

$$\theta = \tan^{-1} \frac{1695.32 - 1160.12}{1268.1} = \tan^{-1} 0.422\ 05 = 22^\circ 52', \text{ for single conductor}$$

Determine the critical positive impulse flashover value and the 60-Hz wet flashover value of the insulator string to be used. Determine the lengths of air gaps that are electrically equivalent to the critical positive impulse flashover, equivalent to the impulse flashover plus 10 percent, and equivalent to the 60-Hz wet flashover. These values may be obtained from catalog data or from the tables in appendix B.

For example:

1. **For 18 insulator units, the critical positive impulse flashover is 1585 kV (table B-7, app. B).**
2. **1585 kV plus 10 percent equals 1744 kV.**
3. **The 60-Hz wet flashover for 18 units is 690 kV (table B-7, app. B).**
4. **The equivalent air gaps for 1., 2., and 3. are 2642, 2921, and 2083 mm (104, 115, and 82 in), respectively (table B-8, app. B).**


1524 mm (5'-0")
Bottom of crossarm
Tower hanger
Insulator string
Conductor elevation at edge of tower, high side of 1:5 ground slope
Conductor elevation at center of tower
Conductor elevation at edge of tower, level span
2438 mm (8'-0")
Conductor elevation at edge of tower, low side of 1:5 ground slope

NOTES:

Conductor = 644 mm^2 (1272 kcmil), ACSR, 45/7.

Sag at 15.5 °C (60 °F) = 13 628 mm (44.71 ft) for a 350.5-m (1150-ft) span.

Conductor elevation at edge of cage:

Metric: 1.219/350.5 = 0.35 % of span ≈ 1.5% of sag = 204 mm.

U.S. Customary: 4/1150 = 0.35 % of span ≈ 1.5% of sag = 0.67 ft = 8.1 in.

Assume ground slope of 1 in 5 equivalent to 244 mm (0.8 ft = 9.6 in) additional sag at edge of tower.

On low side of tower, total drop of conductor at edge of tower = 448 mm (17.7 in).

On high side of tower, assume conductor sag cancels effect of ground slope.

Figure 47.–Assumed dimensions for side view of structure at conductor elevation. 104-D-1073.

Figure 47 shows the assumed dimensions of the sideview of the tower at the conductor elevation. Clearance patterns for two structure types, a tangent structure and an angle structure capable of taking line angles between 5° and 15°, have been constructed for two cases: (1) for duplex conductor, and (2) a single conductor. These clearance patterns are shown on figures 48, 49, 50, and 51.

The clearance pattern shown on figure 48 has been noted to illustrate the following discussion on construction of the clearance pattern. After selecting a scale, begin constructing the pattern by striking a 180° arc with a radius equal to the length of the insulator string as it hangs normally; the center of the arc represents the attachment point of the insulator string at the tower. By looking at a side view of the tower (fig. 47), it can be seen that the electrical clearance between the conductor and steel will be most critical at the edge of the tower because of the sag in the conductor. To account for this, draw a second arc parallel to the first, but with the radius increased by the amount of the conductor sag at the edge of the tower. These arcs represent the possible locations of the conductor (short radius at the centerline of the tower, and long radius at the edge of the tower) at the end of the insulator string, or the centerline between conductors if duplex conductors are used. Draw radii representing the insulator string as it hangs normally and at its positions with the different wind

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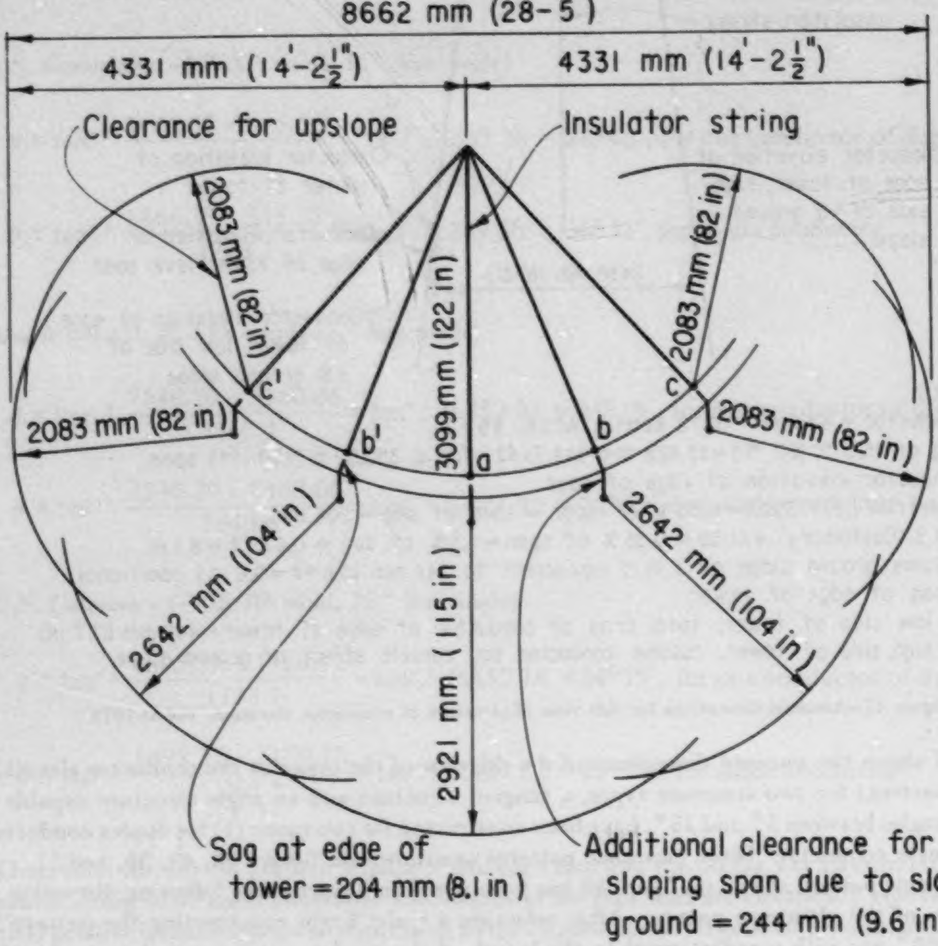
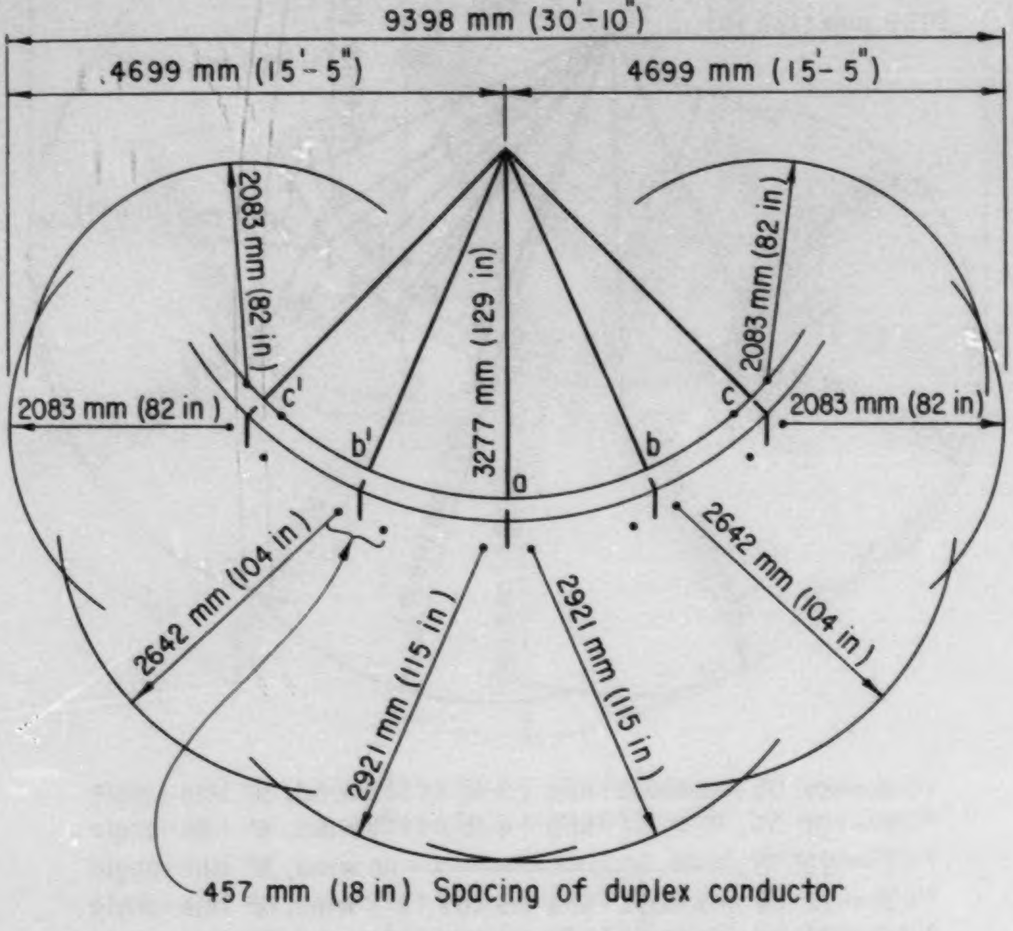
pressures and line angles, as applicable. Locate the points showing the conductor locations at the edge of the tower (fig. 47) for the applicable conditions. From these adjusted conductor locations, strike arcs to form an envelope around the conductor points. The radii for these arcs are the equivalent air gaps previously determined. From the "no-wind" position of the conductor, the arc has a radius equal to the air gap equivalent of the insulator impulse value plus 10 percent. The radius of the arc drawn from the 0.19-kPa (4-lb/ft^2) "wind" position is the air gap equivalent of the insulator impulse


8662 mm (28'-5")
4331 mm (14'-2½")
4331 mm (14'-2½")
Clearance for upslope
Insulator string
2083 mm (82 in)
2083 mm (82 in)
3099 mm (122 in)
c'
c
2083 mm (82 in)
2083 mm (82 in)
b'
a
b
2642 mm (104 in)
2642 mm (104 in)
2921 mm (115 in)
Sag at edge of tower = 204 mm (8.1 in)
Additional clearance for sloping span due to sloping ground = 244 mm (9.6 in)

a = 0° ——— no wind, 0° line angle
b = 22° 07', 0.19152-kPa (4-lb / ft^2) wind, 0° line angle
c = 42° 27', 0.43092-kPa (9-lb / ft^2) wind, 0° line angle
b' = -22° 07', -0.19152-kPa (-4-lb / ft^2) wind, 0° line angle
c' = -42° 27', -0.43092-kPa (-9-lb / ft^2) wind, 0° line angle

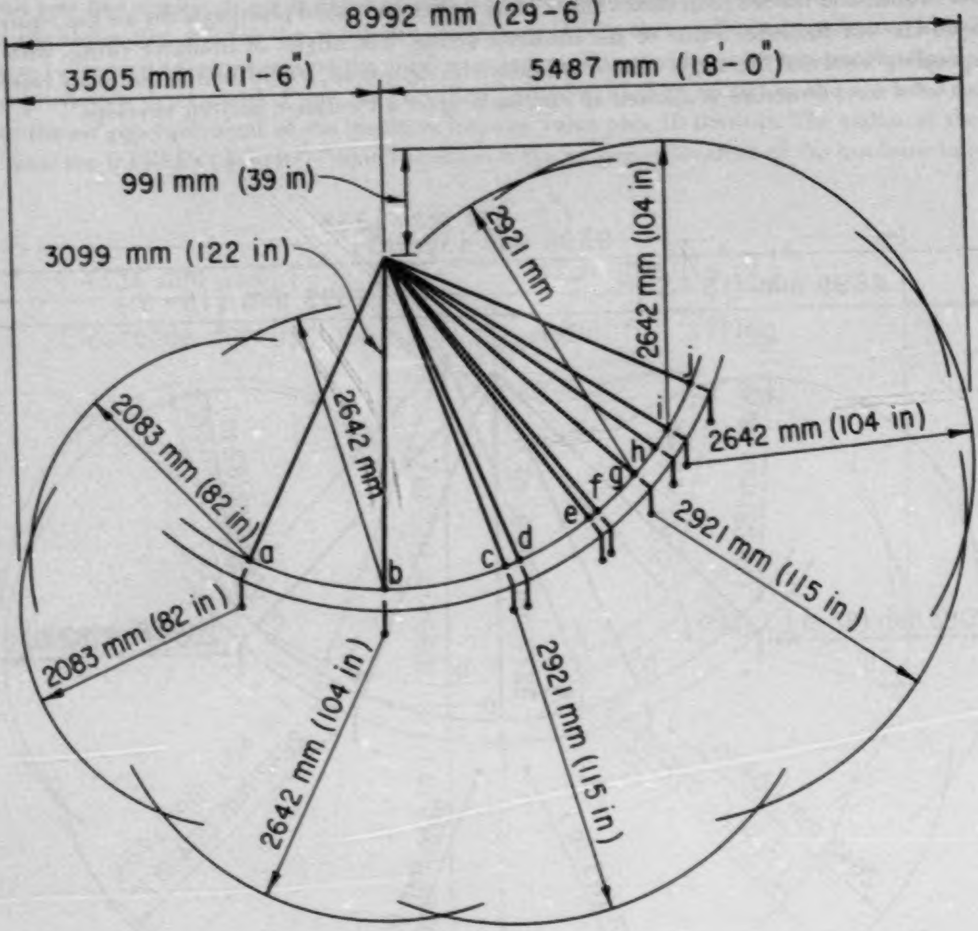
Figure 48.–Clearance pattern for a 30S tangent structure with single conductor. 104-D-1074.

flashover value, and the arc radius from the 0.43-kPa (9-lb/ft²) wind position is the air gap equivalent of the 60-Hz wet flashover value of the insulator string. The angles of insulator swing, with their corresponding wind and line angle values, are shown on figures 48, 49, 50, and 51 for ready reference. No part of a steel structure is allowed to encroach upon a clearance pattern envelope.


9398 mm (30'-10")
4699 mm (15'-5")
4699 mm (15'-5")
2083 mm (82 in)
2083 mm (82 in)
3277 mm (129 in)
2083 mm (82 in)
2083 mm (82 in)
c'
c
b'
b
a
2642 mm (104 in)
2642 mm (104 in)
2921 mm (115 in)
2921 mm (115 in)
457 mm (18 in) Spacing of duplex conductor

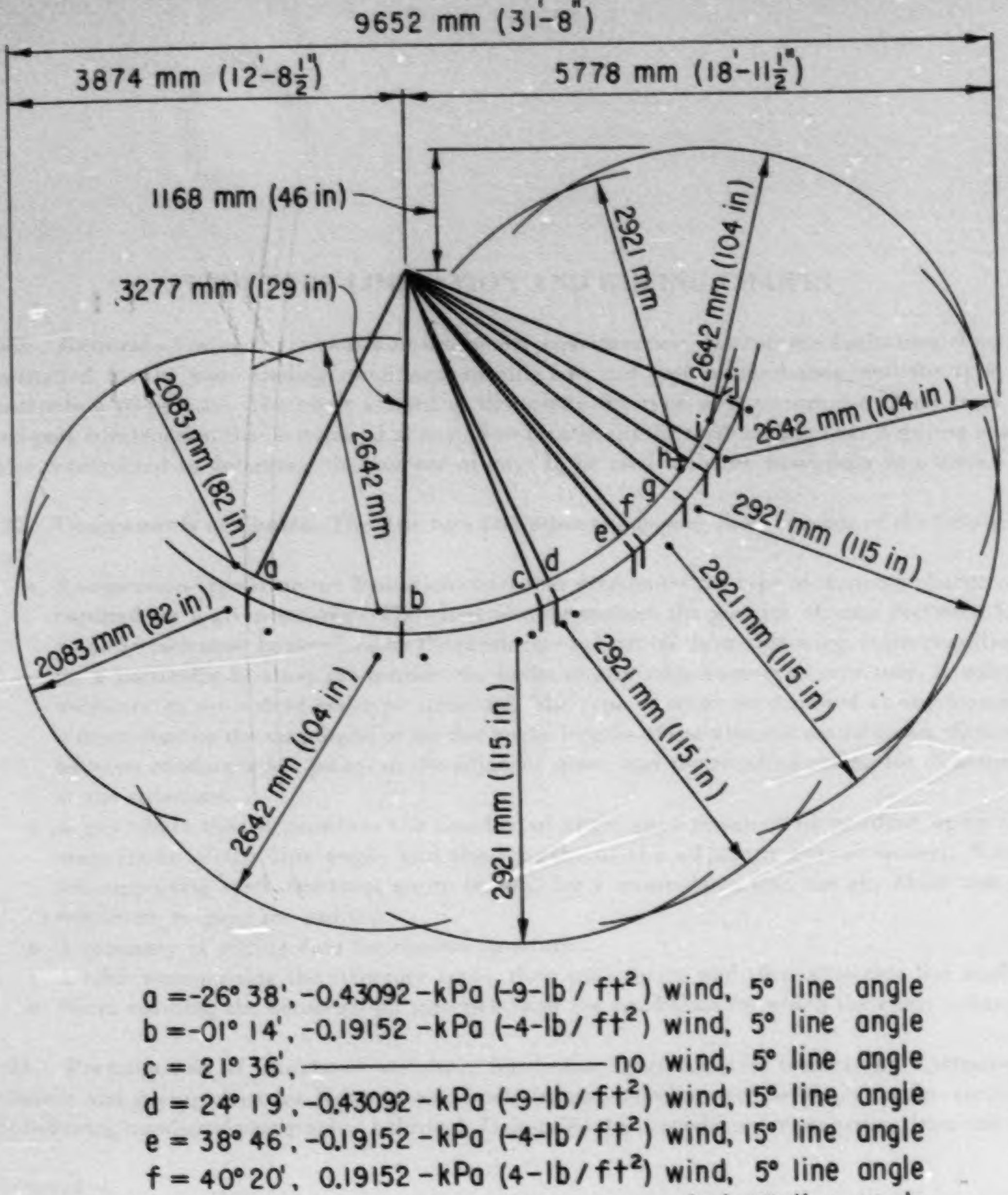
a = 0° , ———————— no wind, 0° line angle
b = 23° 32', 0.19152-kPa (4-lb / ft²) wind, 0° line angle
c = 44° 25', 0.43092-kPa (9-lb / ft²) wind, 0° line angle
b' = -23° 32', -0.19152-kPa (-4-lb / ft²) wind, 0° line angle
c' = -44° 25', -0.43092-kPa (-9-lb / ft²) wind, 0° line angle

Figure 49.—Clearance pattern for a 30S tangent structure with duplex conductor. 104-D-1075.


8992 mm (29'-6")
3505 mm (11'-6")
5487 mm (18'-0")
991 mm (39 in)
3099 mm (122 in)
2921 mm
2642 mm (104 in)
2083 mm (82 in)
2642 mm
2642 mm (104 in)
2921 mm (115 in)
2083 mm (82 in)
2642 mm (104 in)
2921 mm (115 in)
a
b
c
d
e
f
g
h
i
j

a = -25° 05', -0.43092-kPa (-9-lb / ft^2) wind, 5° line angle
b = -01° 09', -0.19152-kPa (-4-lb / ft^2) wind, 5° line angle
c = 20° 18', ———— no wind, 5° line angle
d = 22° 52', -0.43092-kPa (-9-lb / ft^2) wind, 15° line angle
e = 36° 51', -0.19152-kPa (-4-lb / ft^2) wind, 15° line angle
f = 38° 24', 0.19152-kPa (4-lb / ft^2) wind, 5° line angle
g = 47° 54', ———— no wind, 15° line angle
h = 53° 42', 0.43092-kPa (9-lb / ft^2) wind, 5° line angle
i = 57° 23', 0.19152-kPa (4-lb / ft^2) wind, 15° line angle
j = 66° 03', 0.43092-kPa (9-lb / ft^2) wind, 15° line angle

Figure 50.–Clearance pattern for a 30A angle structure with single conductor. 104-D-1076.


9652 mm (31'-8")
3874 mm (12'-8½")
5778 mm (18'-11½")
1168 mm (46 in)
3277 mm (129 in)
2083 mm (82 in)
2642 mm
2921 mm
2642 mm (104 in)
2642 mm (104 in)
2921 mm (115 in)
2921 mm (115 in)
2083 mm (82 in)
2642 mm (104 in)
2921 mm (115 in)
2921 mm (115 in)
a
b
c
d
e
f
g
h
i
j

a = -26° 38', -0.43092-kPa (-9-lb/ft²) wind, 5° line angle
b = -01° 14', -0.19152-kPa (-4-lb/ft²) wind, 5° line angle
c = 21° 36', ——————— no wind, 5° line angle
d = 24° 19', -0.43092-kPa (-9-lb/ft²) wind, 15° line angle
e = 38° 46', -0.19152-kPa (-4-lb/ft²) wind, 15° line angle
f = 40° 20', 0.19152-kPa (4-lb/ft²) wind, 5° line angle
g = 49° 51', ——————— no wind, 15° line angle
h = 55° 34', 0.43092-kPa (9-lb/ft²) wind, 5° line angle
i = 59° 09', 0.19152-kPa (4-lb/ft²) wind, 15° line angle
j = 67° 29', 0.43092-kPa (9-lb/ft²) wind, 15° line angle

Figure 51.–Clearance pattern for a 30A angle structure with duplex conductor. 104-D-1077.

STRUCTURE LIMITATION AND GUYING CHARTS

22. General.–For each transmission line under consideration, a structure limitation chart is constructed for the main loading conditions, specific size and type of conductor, and the type of construction to be used. The chart is used to determine the type of structure for either steel or wood-pole construction that is required at any given location in the transmission line. A guying chart is also constructed to determine the number of guys to be used with the wood-pole structures.

23. Components of Charts.–The structure limitation and guying chart consists of the following items:

- A suspension-type structure limitation chart that determines the type of suspension structure required for a given location. The chart also determines the amount of mass (between low points) which must be provided by the conductor to limit insulator sideswing. If the conditions for a particular location are outside the limits of any suspension-type structure, it will be necessary to use a dead-end-type structure. The type of structure required at any location is dependent on the magnitude of the line angle, lengths of the adjacent actual spans, distance between conductor low points in the adjacent spans, and the required conductor clearances at the structure.
- A guy chart that determines the number of angle guys required (dependent upon the magnitude of the line angle and the lengths of the adjacent actual spans). When self-supporting steel structures are to be used for a transmission line, the guy chart and all references to guys are omitted.
- A summary of guying data for tension structures.
- A table summarizing the structure types, their span limits, and their allowable line angles.
- Notes covering the construction materials, and the conditions on which the chart is based.

24. Preparation of Charts.–A structure limitation chart for steel towers and a structure limitation and guying chart for H-frame, wood-pole transmission lines are developed in this section. The following numbered paragraphs (1 through 7) describe the procedures for preparing these charts.

Paragraph 1.

In order to establish a basis for preparing these charts, the following standards have been established:

a. For steel structures, the permissible sideswing of each insulator string on a suspension-type structure is determined from the clearance pattern established for the design of the towers. The clearance pattern depends on the size and type of conductor and loading conditions for which the transmission line is being designed. Calculations for determining the strength limits of insulator strings shall be based on full-load conditions and the following minimum factors of safety:

Insulator strings (suspension)	2.5
Insulator strings (tension)	3.0

The maximum sum of adjacent spans, the maximum distance between low points of adjacent spans, and the maximum line deflection angle are established as required for the transmission line and the steel towers are designed to fit these structure requirements.

b. Except in California, the design of all wood-pole transmission lines for 69-kV and higher voltages and for important lines of lower voltages shall be in accordance with grade B construction as shown in the latest edition of NESC. Loading conditions and conductor and overhead ground wire tensions shall also be in accordance with the latest edition of the code, except as modified by figure 1 or by specific heavier loading conditions than those prescribed for the general area for which a line is being designed.

The recommended maximum design tensions (full-load tensions based on 33-1/3 percent of the conductor ultimate strength at minus 18 °C (0 °F) under initial conditions) for typical conductors used on transmission lines with H-frame, wood-pole structures are shown in the following tabulation:

ACSR, 24/7 conductors		*Maximum allowable tensions*	
mm^2	(kcmil)	N	(lb)
242	(477)	33 362	(7 500)
282	(556.5)	35 585	(8 000)
306	(605)	37 810	(8 500)
322	(636)	40 034	(9 000)
403	(795)	44 482	(10 000)

Maximum full-load conductor tension on standard USBR H-frame, wood-pole structures should not exceed 44 482 N (10 000 lb).

Strength calculations for determining permissible span lengths, distance between low points, guying, and requirements for double insulator strings shall be based on the full-load conditions shown in paragraph 2 and the minimum factors of safety shown in table 19.

Selection of the proper type of suspension structure for any location shall be based on a loading condition of 0.19-kPa (4-lb/ft^2) wind pressure on the bare conductor at 15.5 °C (60 °F) in all loading zones. The three axes of the structure limitation chart shall be calibrated to correspond to the values of this loading condition. Table 20 shows the minimum clearance from the conductor to the pole ground wire or to the surface of the crossarm; these clearances shall be maintained under the loading condition above.

If a pole ground wire is not used, the clearances specified to the pole ground wire in table 20 shall be maintained to the centerline of the poles. The limits for permissible insulator swing on the different types of structures are shown for the various voltage classes in table 21. Drawings of some of the different types of wood structures are shown later in this section.

Table 19.–*Minimum factors of safety for wood-pole construction*[1] *(grade B)*

	At full load	At 15.5 °C (60 °F), no wind
Wood poles	2.0	[3]5.5
Crossarms	4.0	[3]5.5
Guys (line)	[2]2.0	
Guys (transverse)	2.67	
Insulator strings (suspension)	[2]2.5	
Insulator strings (tension)	3.0	
Insulator pins (bending)	3.0	
Conductor	2.0	4.0

[1] Factors of safety are based on ultimate strengths of the different materials to which they are applicable.

[2] USBR standard.

[3] Based on 8.96-MPa (1300-lb/in²) fiber stress for fir, or 6.89-MPa (1000-lb/in²) fiber stress for western red cedar.

Table 20.–*Conductor clearance to pole ground wire or crossarm surface–wood-pole construction*

Type of construction, kV	Conductor clearance			
	Pole ground wire[1]		Crossarm surface[1]	
	mm	(in)	mm	(in)
69	660	(26)	508	(20)
115	1092	(43)	889	(35)
138	1245	(49)	991	(39)
161	1524	(60)	1245	(49)
230	1803	(71)	1473	(58)

[1] USBR standard.

Table 21.–*Angular limitations of suspension insulator swing for standard USBR wood-pole structures*

Structure type	Angular limitation, degrees				
	69 kV	115 kV	138 kV	161 kV	230 kV
HS	[2]54 max.	36 max.	40 max.	38 max.	42 max.
HSB	[2]54 max.	36 max.	40 max.	38 max.	42 max.
3A	30 min.	36 min.	39 min.	45 min.	47 min.
3AB	12 min.	24 min.	27 min.	35 min.	38 min.
3AC[1]	−30 to +70	−16 to +70	−28 to +70	−16 to +63	−17 to +60
3AD[1]	−30 to +70	−16 to +70	−28 to +70	−16 to +63	−17 to +60

[1] Structure types 3AC and 3AD should not be used where either a type 3A or 3AB will satisfy the requirements of the proposed structure location.

[2] Extreme care should be exercised in checking for uplift.

The following minimum clearance between conductor and guy wire shall be maintained at all conductor positions on wood-pole construction:

Type of construction kV	*Clearance*[1] mm	(in)
69	965	(38)
115	1397	(55)
138	1524	(60)
161	1676	(66)
230	1956	(77)

[1] USBR standard.

In areas where conductors and overhead ground wires are subject to ice loading, the maximum length of a single span should be limited to prevent contact between conductors or between conductors and overhead ground wires due to galloping conductors. For span lengths up to 183 m (600 ft), full-sag ellipses should be used to determine the required clearances. For longer spans, one-half-sag ellipses may be used.

c. In California, the design of wood-pole transmission lines shall be in accordance with grade B construction as shown in General Order No. 95 of the California Public Utilities Commission [1],[1] except that grade A construction is required for crossings over railroads and major communication lines.

Loading conditions and conductor and overhead ground wire tensions shall also be in accordance with General Order No. 95, except as modified by figure 1.

The recommended maximum design tensions (full-load tensions based on 33-1/3 percent of the conductor ultimate strength at minus 18 °C (0 °F) under initial conditions) for typical conductors used on transmission lines in California with H-frame, wood-pole structures are shown in the following tabulation:

ACSR, 24/7 conductors		*Maximum allowable tensions*	
mm^2	(kcmil)	N	(lb)
242	(477)	33 362	(7 500)
282	(556.5)	35 585	(8 000)
306	(605)	37 810	(8 500)
322	(636)	40 034	(9 000)
403	(795)	44 482	(10 000)

Maximum full-load conductor tension on standard USBR H-frame-type structures in California should not exceed 44 482 N (10 000 lb).

Strength calculations for determining permissible span lengths, distance between low points, guying, and requirements for double insulator strings shall be based on the full-load conditions shown in paragraph 2 and the minimum factors of safety shown in table 22.

---

[1] Numbers in brackets refer to items in the Bibliography.

Table 22.–*Minimum factors of safety for wood-pole construction in California*[1]

	Grade A	Grade B
Wood poles	4.0	3.0
Crossarms	[2]4.0	[2]4.0
Guys, except in light loading rural areas	2.0	2.0
Guys in light loading rural areas	2.0	1.5
Insulator strings (suspension)	3.0	[2]2.5
Insulator strings (tension)	3.0	[2]3.0
Insulator pins (bending)	[2]3.0	[2]3.0
Conductor	2.0	2.0

[1] Factors of safety are based on ultimate strengths of the different materials to which they are applicable.

[2] USBR standard.

Selection of the proper type of suspension structure for any location shall be based on conditions at 15.5 °C (60 °F) with a 0.19-kPa (4-lb/ft^2) wind pressure in all loading areas. The three axes of the structure limitation chart shall be calibrated to correspond to the values at the above conditions. Table 23 shows the minimum clearance from the conductor to the pole ground wire or to the surface of the crossarm; these clearances shall be maintained under the above loading condition.

Table 23.–*Conductor clearance to pole ground wire or crossarm surface–wood-pole construction in California*

Type of construction, kV	Conductor clearance			
	Pole ground wire[1]		Crossarm surface[1]	
	mm	(in)	mm	(in)
69	660	(26)	508	(20)
115	1092	(43)	889	(35)
138	1245	(49)	991	(39)
161	1524	(60)	1245	(49)
230	1803	(71)	1473	(58)

[1] USBR standard.

If a pole ground wire is not used, the clearances specified to the pole ground wire in table 23 shall be maintained to the centerline of the poles.

The limits for permissible insulator swing in California are the same as shown in table 21.

The following minimum clearance between conductor and guy wire shall be maintained at all conductor positions:

Type of construction kV	*Clearance*[1]	
	mm	(in)
69	965	(38)
115	1397	(55)
138	1524	(60)
161	1676	(66)
230	1956	(77)

---

[1] USBR standard.

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In areas of California where conductors and overhead ground wires are subject to ice loading, the maximum length of a single span should be limited to prevent contact between conductors or between conductors and overhead ground wires due to galloping conductors. For span lengths up to 183 m (600 ft), full-sag ellipses should be used to determine the required clearance. For longer spans, one-half-sag ellipses may be used.

Paragraph 2.
Full-load conditions are as follows:

National Electrical Safety Code or California General Order No. 95	Loading for calculations of strength of structures and their components
Light loading districts[1] : 0.43-kPa (9-lb/ft²) wind pressure, no ice, plus constant, at -1 °C (30 °F)	0.57-kPa (12-lb/ft²) wind pressure, no ice[1]
Medium loading districts[1] : 0.19-kPa (4-lb/ft²) wind pressure, 6-mm (1/4-in) ice, plus constant, at -9.5 °C (15 °F)	0.38-kPa (8-lb/ft²) wind pressure, 6-mm (1/4-in) ice[1]
Heavy loading districts[1] : 0.19-kPa (4-lb/ft²) wind pressure, 13-mm (1/2-in) ice, plus constant, at - 18 °C (0 °F)	0.38-kPa (8-lb/ft²) wind pressure, 13-mm (1/2-in) ice[1]
California light loading: 0.38-kPa (8-lb/ft²) wind pressure, no ice, at -4 °C (25 °F)	0.38-kPa (8-lb/ft²) wind pressure, no ice
California heavy loading: 0.29-kPa (6-lb/ft²) wind pressure, 13-mm (1/2-in) ice, at - 18 °C (0 °F)	0.29-kPa (6-lb/ft²) wind pressure, 13-mm (1/2-in) ice

---

[1] Extreme wind loading as shown on NESC figure 250-2 in reference [3] should be used if resultant loading is greater.

Paragraph 3.
The data required for construction of a structure limitation chart for the design of a steel structure transmission line are discussed at the beginning of section 21, which covers conductor clearance patterns. The clearance patterns themselves are important because they indicate the maximum design

swing of the suspension insulator strings on the various types of structures; these swing angles become limitation lines on the low-point portion of the structure limitation chart. The balance of the data previously discussed are basically tabled data, although the maximum low-point distance and the maximum sum of adjacent spans limitations are drawn on the chart. An example problem follows that shows the procedure for obtaining the data for the steel structure limitation chart.

Example Problem **(steel construction)**

Assume a 345-kV transmission line with a 644-mm^2 (1272-kcmil), ACSR, 45/7 duplex conductor. Assume the line location is in an area with a 0.77-kPa (16-lb/ft^2) extreme wind pressure. This wind pressure will not be a factor because the resultant force per unit length for the conductor would be 18.746 N/m (1.285 lb/ft), which is less than 27.5345 N/m (1.8867 lb/ft) for NESC full-load conditions. The extreme wind pressure was assumed here for example purposes. The following data are also assumed:

Maximum initial full-load (NESC heavy) tension per conductor = 63 165 N (14 200 lb)
Ruling span = 350.5 m (1150 ft)
20 insulator units per string
  146 by 267 mm (5-3/4 by 10-1/2 in)
  Length per string = 3556 mm (140 in)
  Vertical force (weight) per string = 1628 N (366 lb)
Wind
  Everyday maximum = 0.19 kPa (4 lb/ft^2)
  Maximum design = 0.48 kPa (10 lb/ft^2)
Design for a minimum low-point distance equal to one-third the sum of adjacent spans.

Drawings of the different types of steel structures are not shown in this manual because new designs are usually made for each transmission line. Steel tower designations and types are:

30S = tangent, suspension, V-string on center phase
30X = tangent to 5° line angle, suspension
30A = angle, 5 to 15° line angle, suspension
30T = tangent to 5° line angle, tension
30D = tangent to 30° line angle, dead end

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Tabular steel tower data follows:

Metric

Tower type	30S	30X	30A	30T	30D
Line angle capability	0°	0°-5°	5°-15°	0°-5°	0°-30°
Ruling span (m)	350.5	350.5	350.5	350.5	350.5
Maximum single span (m)					
Minimum line angle	396	487.5	487.5	548.5	640
Maximum line angle	396	396	396	487.5	
Maximum sum of adjacent spans (m)					
Minimum line angle	792.5	975.5	975.5	1097	1280
Maximum line angle	792.5	792.5	792.5	975.5	
Maximum low point distance (m)					
Conductor, minimum line angle	731.5	975.5	975.5	1280	1371.5
Conductor, maximum line angle	731.5	792.5	792.5	1280	
OGW, minimum line angle	853.5	1036.5	1036.5	1524	1463
OGW, maximum line angle	853.5	853.5	853.5	1524	
Maximum uplift (N)					
Conductor, minimum line angle				305	305
Conductor, maximum line angle				213.5	
OGW, minimum line angle				396	396
OGW, maximum line angle				254	
Body heights (m)	19.8 and 25.9	19.8 and 25.9	19.8 and 25.9	16.8 and 22.9	16.8 and 22.9
Leg extension range (m), at 0.762-m intervals	1.524 to 10.67	1.524 to 10.67	1.524 to 10.67	1.524 to 10.67	1.524 to 10.67

U.S. Customary

Tower type	30S	30X	30A	30T	30D
Line angle capability	0°	0°-5°	5°-15°	0°-5°	0°-30°
Ruling span (ft)	1150	1150	1150	1150	1150
Maximum single span (ft)					
Minimum line angle	1300	1600	1600	1800	2100
Maximum line angle	1300	1300	1300	1600	
Maximum sum of adjacent spans (ft)					
Minimum line angle	2600	3200	3200	3600	4200
Maximum line angle	2600	2600	2600	3200	
Maximum low point distance (ft)					
Conductor, minimum line angle	2400	3200	3200	4200	4500
Conductor, maximum line angle	2400	2600	2600	4200	
OGW, minimum line angle	2800	3400	3400	5000	4800
OGW, maximum line angle	2800	2800	2800	5000	
Maximum uplift (lb)					
Conductor, minimum line angle				1000	1000
Conductor, maximum line angle				700	
OGW, minimum line angle				1300	1300
OGW, maximum line angle				833	
Body heights (ft)	65 and 85	65 and 85	65 and 85	55 and 75	55 and 75
Leg extension range (ft), at 2.5-ft intervals	5 to 35	5 to 35	5 to 35	5 to 35	5 to 35

Calculations for the strength requirements of insulator strings for the various types of steel towers are as follows:

Type 30S, 0° line angle

Maximum low-point distance = 731.5 m (2400 ft)
Maximum sum of adjacent spans = 792.5 m (2600 ft)
Conductor force with 13 mm (1/2 in) of radial ice = 37.676 N/m (2.5816 lb/ft)
0.38-kPa (8-lb/ft²) wind on iced conductor = 22.816 N/m (1.5634 lb/ft)

The conductor force values are shown on figures 52 and 53. The force values shown above for a 0.38-kPa wind are simply twice the values shown on these figures for a 0.19-kPa wind.

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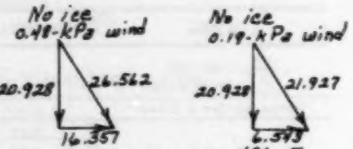
INITIAL
FINAL
SAG CALCULATIONS

CONDUCTOR 644 mm² ACSR 45/7
Code Name Bittern
Rated Breaking Strength 151 684 N
Diameter 34 mm
Tension Limitations:
Initial, ___°C, 33⅓ %, ___ N
Final, ___°C, 25 %, ___ N
Loaded, ___°C, 50 %, ___ N
Final, 15.5°C, ___ %, ___ N
Computed by ___ Date ___

LOADING Heavy
Linear Force Factor: *K = 4.5241
Dead Load Force (W') 20.928 N/m
13 mm Ice (W'') 37.676 N/m
0.19152 kPa Wind 11.408 N/m
Resultant: (W''') 43.889 N/m
Area (A) 689 mm²
Temp. Coeff. of Linear Exp.:
0.000 0207 per°C
*1977 NESC K=4.3782



Permanent Set 0.000 486 5
Creep 0.000 554 1
Total 0.001 040 6

Modulus, (E) Final 64.466 GPa
Initial 46.212 GPa
Final AE 44 419 065 N
Initial AE 31 841 495 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	SW/AE	SW/T	SAG FACTOR	SAG, mm	SW, N	TENSION, N
			SPAN LENGTH(S) 350.5 m					
13 mm Ice 0.19152 kPa Wind (W''')	-18	1.000 530	0.000 483 1	0.2435	0.030 70	10 760	15 383.09	63 165 I
Permanent Set & Creep		0.001 041						
No Ice, No Wind (W')	-18	1.001 571	0.000 165 1	0.2321	0.029 29	10 249	7335.26	31 604 F
	-1	1.001 916	0.000 165 1	0.2471	0.031 16	10 922	7335.26	29 685
	15.5	1.002 261	0.000 165 1	0.2612	0.032 98	11 559	7335.26	28 093
	32	1.002 606	0.000 165 1	0.2746	0.034 71	12 166	7335.26	26 713
	49	1.002 951	0.000 165 1	0.2876	0.036 39	12 755	7335.26	25 505
			SPAN LENGTH(S) 350.5 m					
0 mm Ice 0.4788 kPa Wind (W''')								
Permanent Set & Creep								
0.4788-kPa No Ice, ~~No~~ Wind (W')	-18							
	-1							
	15.5	1.002 261	0.000 209 6	0.2676	0.033 80	11 847	9309.98	34 791 F
	32							
	49							
			SPAN LENGTH(S) 350.5 m					
0 mm Ice 0.19152 kPa Wind (W''')								
Permanent Set & Creep								
0.19152-kPa No Ice, ~~No~~ Wind (W')	-18							
	-1							
	15.5	1.002 261	0.000 173 0	0.2624	0.033 13	11 612	7685.41	29 289 F
	32							
	49							

Figure 52.–Conductor sag and tension calculation form for example problem on steel structure limitation chart (metric).

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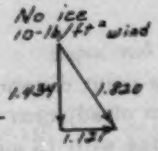

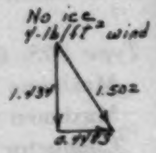

INITIAL
FINAL SAG CALCULATIONS

LOADING Heavy
Jw K = 0.31

CONDUCTOR 1272 kcmil ACSR 45/7
Code Name Bittern
Rated Breaking Load 34 100 lb
Diameter 1.345 inch
Tension Limitations:
Initial, ____ °F 33⅓ % ________ lb
Final, ____ °F 25 % ________ lb
Loaded, ____ °F 50 % ________ lb
Final, 60 °F ____ % ________ lb
Computed by ________ Date ________

Weight Factors:
Dead Weight (W') 1.4340 lb/ft
+ 1/2 in. Ice (W'') 2.5816 lb/ft
4 lb Wind 0.7817 lb/ft
Resultant: (W''') 3.0073 lb/ft
Area (A) 1.068 in²
Temp. Coeff. of Linear Exp.: * 1977 NESC
0.000 011 5 per °F K = 0.30

Permanent Set 0.000 486 5
Creep 0.000 554 1
Total 0.001 040 6

Modulus, (E) Final 9.35 x 10⁶ lb/in²
Initial 6.702 x 10⁶ lb/in²
Final AE 9 985 800 lb
Initial AE 7 159 270 lb

LOADING	TEMP °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
SPAN LENGTH(S) 1150 FEET								
1/2 inch Ice, 4 lb/ft² Wind(W''')	0	1.000 530	0.000 483 1	0.2435	0.030 70	35.31	3458.4	14 200 I
Permanent Set & Creep		0.001 041						
No Ice, No Wind (W')	0	1.001 571	0.000 165 1	0.2321	0.029 24	33.63	1649.1	7105 F
	30	1.001 916	0.000 165 1	0.2471	0.031 16	35.83	1649.1	6 674
	60	1.002 261	0.000 165 1	0.2612	0.032 98	37.93	1649.1	6 314
	90	1.002 606	0.000 165 1	0.2746	0.034 71	39.92	1649.1	6 005
	120	1.002 951	0.000 165 1	0.2876	0.036 39	41.85	1649.1	5 734
SPAN LENGTH(S) 1150 FEET								
0 inch Ice, 10 lb/ft² Wind(W''')								
Permanent Set & Creep								
10 lb/ft² No Ice, ~~No~~ Wind (W')	0							
	30							
	60	1.002 261	0.000 209 6	0.2676	0.033 80	38.87	2093.0	7821 F
	90							
	120							
SPAN LENGTH(S) 1150 FEET								
0 inch Ice, 4 lb/ft² Wind(W''')								
Permanent Set & Creep								
4 lb/ft² No Ice, ~~No~~ Wind (W')	0							
	30							
	60	1.002 261	0.000 173	0.2624	0.033 13	38.10	1727.3	6583 F
	90							
	120							

Figure 53.–Conductor sag and tension calculation form for example problem on steel structure limitation chart (U.S. customary).

Metric

Maximum vertical load = (731.52) (37.676) = 27 560.75 newtons per conductor
Maximum wind load = (792.48/2) (22.816) = 9040.61 newtons per conductor
Resultant load = $[(27\,560.75)^2 + (9040.61)^2]^{1/2}$ = 29 005.65 newtons per conductor
= 58 011.30 newtons per phase
= 145 028.25 newtons per phase with a safety factor of 2.5

Use 177 928-N insulator units for suspension strings.

A sketch of a center phase V-string attachment for the 30S tower is shown on figure 54.

For center phase V-string,

$$\frac{a}{\sin A} = \frac{b}{\sin B}$$

$$\frac{145\,028}{\sin 80^\circ} = \frac{b}{\sin 50^\circ}$$

$$b = \frac{145\,028\,(0.766\,04)}{0.984\,81} = 112\,810.85 \text{ N}$$

Use 133 446-N insulator units.

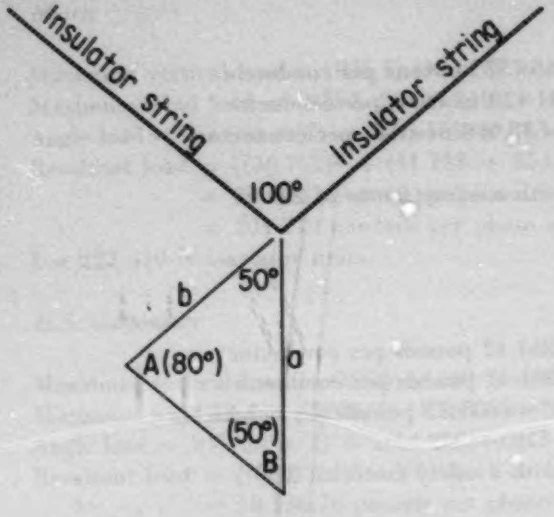

Figure 54.–Center phase V-string for type 30S steel structure with no line angle.

U.S. Customary

Maximum vertical load = (2400) (2.5816) = 6195.84 pounds per conductor
Maximum wind load = (2600/2) (1.5634) = 2032.42 pounds per conductor
Resultant load = $[(6195.84)^2 + (2032.42)^2]^{1/2}$ = 6520.67 pounds per conductor
= 13 041.34 pounds per phase
= 32 603.34 pounds per phase with a safety factor of 2.5
Use 40 000-lb insulator units for suspension strings.

For center phase V-string (fig. 54),

$$\frac{a}{\sin A} = \frac{b}{\sin B}$$

$$\frac{32\,603}{\sin 80^\circ} = \frac{b}{\sin 50^\circ}$$

$$b = \frac{32\,603\,(0.766\,04)}{0.984\,81} = 25\,360.57 \text{ lb}$$

Use 30 000-lb insulator units.

Type 30X, 0° line angle
Maximum low-point distance = 975.5 m (3200 ft)
Maximum sum of adjacent spans = 975.5 m (3200 ft)

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Metric

Maximum vertical load = (975.5) (37.676) = 36 752 newtons per conductor
Maximum wind load = (975.5/2) (22.816) = 11 128 newtons per conductor
Resultant load = $[(36\ 752)^2 + (11\ 128)^2]^{1/2}$ = 38 400 newtons per conductor
= 76 800 newtons per phase
= 192 000 newtons per phase with a safety factor of 2.5
Use 222 410-N insulator units.

U.S. Customary

Maximum vertical load = (3200) (2.5816) = 8261.12 pounds per conductor
Maximum wind load = (3200/2) (1.5634) = 2501.44 pounds per conductor
Resultant load = $[(8261.12)^2 + (2501.44)^2]^{1/2}$ = 8631.53 pounds per conductor
= 17 263.06 pounds per phase
= 43 157.65 pounds per phase with a safety factor of 2.5
Use 50 000-lb insulator units.

Type 30X, 5° line angle
Maximum low-point distance = 792.5 m (2600 ft)
Maximum sum of adjacent spans = 792.5 m (2600 ft)

Metric

Maximum vertical load = (792.5) (37.676) = 29 858 newtons per conductor
Maximum wind load = (792.5/2) (22.816) = 9040 newtons per conductor
Angle load = $2T(\sin \alpha/2)$ = 2(63 165) (0.043 62) = 5510 newtons per conductor
Resultant load = $[(29\ 858)^2 + (9040 + 5510)^2]^{1/2}$ = 33 214 newtons per conductor
= 66 428 newtons per phase
= 166 070 newtons per phase with a safety factor of 2.5
Use 177 928-N insulator units.

U.S. Customary

Maximum vertical load = (2600) (2.5816) = 6712.16 pounds per conductor
Maximum wind load = (2600/2) (1.5634) = 2032.42 pounds per conductor
Angle load = $2T(\sin \alpha/2)$ = 2(14 200) (0.043 62) = 1238.81 pounds per conductor
Resultant load = $[(6712.16)^2 + (2032.42 + 1238.81)^2]^{1/2}$ = 7466.86 pounds per conductor
= 14 933.72 pounds per phase
= 37 334.3 pounds per phase with a safety factor of 2.5
Use 40 000-lb insulator units.

Type 30A, 5° line angle
Maximum low-point distance = 975.5 m (3200 ft)
Maximum sum of adjacent spans = 975.5 m (3200 ft)

Metric

Maximum vertical load = (975.5) (37.676) = 36 752 newtons per conductor
Maximum wind load = (975.5/2) (22.816) = 11 128 newtons per conductor
Angle load = $2T(\sin \alpha/2)$ = 2(63 165) (0.043 62) = 5510 newtons per conductor
Resultant load = $[(36\ 752)^2 + (11\ 128 + 5510)^2]^{1/2}$ = 40 342 newtons per conductor
= 80 684 newtons per phase
= 201 710 newtons per phase with a safety factor of 2.5
Use 222 410-N insulator units.

U.S. Customary

Maximum vertical load = (3200) (2.5816) = 8261.12 pounds per conductor
Maximum wind load = (3200/2) (1.5634) = 2501.44 pounds per conductor
Angle load = $2T(\sin \alpha/2)$ = 2(14 200) (0.043 62) = 1238.81 pounds per conductor
Resultant load = $[(8261.12)^2 + (2501.44 + 1238.81)^2]^{1/2}$ = 9068.38 pounds per conductor
= 18 136.76 pounds per phase
= 45 341.9 pounds per phase with a safety factor of 2.5
Use 50 000-lb insulator units.

Type 30A, 15° line angle
Maximum low-point distance = 792.5 m (2600 ft)
Maximum sum of adjacent spans = 792.5 m (2600 ft)

Metric

Maximum vertical load = (792.5) (37.676) = 29 858 newtons per conductor
Maximum wind load = (792.5/2) (22.816) = 9040 newtons per conductor
Angle load = $2T(\sin \alpha/2)$ = 2(63 165) (0.130 53) = 16 489 newtons per conductor
Resultant load = $[(29\ 858)^2 + (9040 + 16\ 489)^2]^{1/2}$ = 39 284 newtons per conductor
= 78 568 newtons per phase
= 196 420 newtons per phase with a safety factor of 2.5
Use 222 410-N insulator units.

U.S. Customary

Maximum vertical load = (2600) (2.5816) = 6712.16 pounds per conductor
Maximum wind load = (2600/2) (1.5634) = 2032.42 pounds per conductor
Angle load = $2T(\sin \alpha/2)$ = 2(14 200) (0.130 53) = 3707.05 pounds per conductor
Resultant load = $[(6712.16)^2 + (2032.42 + 3707.05)^2]^{1/2}$ = 8831.46 pounds per conductor
= 17 662.92 pounds per phase
= 44 157.3 pounds per phase with a safety factor of 2.5
Use 50 000-lb insulator units.

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Type 30T and 30D tension structures

Metric

Maximum tension = 63 165 newtons per conductor
= 126 330 newtons per phase
= 378 990 newtons per phase with a safety factor of 3.0

Use double strings of 222 410-N insulator units.

U.S. Customary

Maximum tension = 14 200 pounds per conductor
= 28 400 pounds per phase
= 85 200 pounds per phase with a safety factor of 3.0

Use double strings of 50 000-lb insulator units.

Make the following calculations (paragraphs 3.a. through 3.g.) to obtain data for use in the construction of the steel structure limitation chart:

a. Calculate the conductor tensions to be used for the loading conditions shown in the following tabulation. The calculations are shown on figures 52 and 53. From these figures, the tensions are as follows:

Loading condition	***Tension***	
	N	**(lb)**
13-mm (1/2-in) ice, 0.19-kPa (4-1b/ft²) wind, - 18 °C (0 °F)	**63 165**	**(14 200)**
No ice, 0.19-kPa wind, 15.5 °C (60 °F)	**29 289**	**(6 583)**
No ice, 0.48-kPa (10-lb/ft²) wind, 15.5 °C	**34 791**	**(7 821)**
No ice, no wind, 15.5 °C	**28 083**	**(6 314)**

b. Assume a scale to be used for the distance between conductor low points (vertical scale below the point of origin), and compute the scale factor:

Metric

Let 1 mm = 7.2 m of bare conductor vertical force.

Vertical force of conductor = 20.928 N/m
Then, 1 mm = (7.2) (20.928) = 150.68 N, and
1 N = 1/150.68 = 0.006 636 58 mm (scale factor).

U.S. Customary

Let 1 in = 600 ft of bare conductor weight.

Weight of conductor = 1.4340 lb/ft
Then, 1 in = (600) (1.434) = 860.4 lb, and
1 lb = 1/860.4 = 0.001 162 25 in (scale factor).

c. Compute the vertical force of the insulator string and convert one-half the insulator force per phase or one-fourth the insulator force per conductor to millimeters (inches) using the low-point scale factor:

Metric

Insulator string force = 1628 N
1628/4 = 407 newtons per conductor
(407) (0.006 636 58) = 2.70 mm

U.S. Customary

Insulator string weight = 366 lb
366/4 = 91.5 pounds per conductor
(91.5) (0.001 162 25)= 0.106 in

d. Compute line deflection angle scale (horizontal axis to the right of the origin) with the degree calibration equal to the resultant tension at 15.5 °C (60 °F) final with 0.48-kPa (10-lb/ft²) wind pressure in one conductor due to the line angle:

$$F_a = 2T(\sin \alpha/2)$$
$$T = 34\,791 \text{ N } (7821 \text{ lb})$$
$$2T = 69\,582 \text{ N } (15\,642 \text{ lb})$$

Assume line angles and compute resultant tensions and their scale values. The scale factor must be the same as that computed in paragraph 3.b.

Line angle (α), degrees	sin α/2	2*T* (sin α/2) N	2*T* (sin α/2) (lb)	Scale mm	Scale (in)
5	0.043 62	3 035	(682)	20	(0.79)
10	.087 16	6 065	(1363)	40	(1.59)
15	.130 53	9 083	(2042)	60	(2.38)
20	.173 65	12 083	(2716)	80	(3.17)
25	.216 44	15 060	(3385)	100	(3.95)
30	.258 82	18 009	(4048)	120	(4.72)
35	.300 71	20 924	(4704)	139	(5.49)
40	.342 02	23 798	(5350)	158	(6.24)
50	.422 62	29 407	(6610)	195	(7.71)
60	.500 00	34 791	(7821)	231	(9.12)

e. Assume scale to be used for the sum of adjacent spans portion of the chart (vertical scale above the point of origin):

Metric

Let
1 mm = 6 m of wind span = one-half the sum of adjacent spans.

Note: This scale will be doubled in marking the chart; that is, 1 mm will equal 12 m so that the sum of adjacent spans may be read directly instead of reading one-half the sum of adjacent spans.

0.48-kPa wind on conductor = 16.357 N/m (from force triangle, fig. 52)
Then, 1 mm = (6) (16.357) = 98.142 N, and
1 N = 1/98.142 = 0.010 189 318 mm (scale factor).

U.S. Customary

Let
1 in = 500 ft of wind span = one-half the sum of adjacent spans.

Note: This scale will be doubled in marking the chart; that is, 1 inch will equal 1000 feet so that the sum of adjacent spans may be read directly instead of reading one-half the sum of adjacent spans.

10-lb/ft^2 wind on the conductor = 1.121 lb/ft (from force triangle, fig. 53)
Then, 1 in = (500) (1.121) = 560.5 lb, and
1 lb = 1/560.5 = 0.001 784 12 in (scale factor).

f. Calculate angle of bias lines to be drawn right and left of the deflection angle calibrations. These bias lines are used to automatically add or subtract the wind pressure to or from the resultant tension due to a line deflection angle. Because the scale factor used for the deflection angle scale must be the same as that used for the low-point scale, the slope of the bias lines may be determined by

$$\tan\theta = \frac{\text{sum of adjacent spans scale factor}}{\text{low-point scale factor}}$$

where
θ is the angle formed by the bias lines with the horizontal axis. The slope of the bias lines will vary depending upon the choice of scale factors previously determined in paragraphs 3.b. and 3.e.

$$\theta = \tan^{-1}\frac{0.010\ 189\ 318}{0.006\ 636\ 58} = \tan^{-1} 1.5353 = 56°55' \text{ (metric)}$$

$$\theta = \tan^{-1}\frac{0.001\ 784\ 12}{0.001\ 162\ 25} = \tan^{-1} 1.5351 = 56°55' \text{ (U.S. customary)}$$

g. Calculate the maximum insulator swing angles in each direction by using maximum positive wind with maximum permitted line angle, and maximum negative wind with minimum permitted line angle for each type of suspension tower:

Vertical load due to conductor low-point distance equal to one-third the sum of adjacent spans plus one-fourth the insulator force per conductor:

For one conductor, $\frac{(350.5)(2)}{3}(20.928) + \frac{1628}{4} = 5297.2$ N, or

$$\frac{(1150)(2)}{3}(1.434) + \frac{366}{4} = 1190.9 \text{ lb}$$

Calculate swing angles for suspension insulator strings:

Metric

For 0.48-kPa wind, 0° line angle (30S tower with positive wind)

$$\text{Wind} = 350.5\ (16.357) = 5733.13 \text{ N}$$

$$\theta = \tan^{-1} \frac{5733.13}{5297.2} = \tan^{-1} 1.0823 = 47^\circ 15'$$

For –0.48-kPa wind, 0° line angle (30S and 30X towers with negative wind)

$$\theta = \tan^{-1} \frac{-5733.13}{5297.2} = \tan^{-1} -1.0823 = -47^\circ 15'$$

For 0.48-kPa wind, 5° line angle (30X tower with positive wind)

$$2T(\sin \alpha/2) = 2\ (34\ 791)\ (0.043\ 62) = 3035.17 \text{ N}$$

$$\theta = \tan^{-1} \frac{3035.17 + 5733.13}{5297.2} = \tan^{-1} 1.6553 = 58^\circ 51'$$

For –0.48-kPa wind, 5° line angle (30A tower with negative wind)

$$\theta = \tan^{-1} \frac{3035.17 - 5733.13}{5297.2} = \tan^{-1} -0.509\ 32 = -26^\circ 59'$$

For 0.48-kPa wind, 15° line angle (30A tower with positive wind)

$$2T(\sin \alpha/2) = 2\ (34\ 791)\ (0.130\ 53) = 9082.28 \text{ N}$$

$$\theta = \tan^{-1} \frac{9082.28 + 5733.13}{5297.2} = \tan^{-1} 2.7968 = 70^\circ 19'$$

U.S. Customary

For 10-lb/ft² wind, 0° line angle (30S tower with positive wind)

$$\text{Wind} = 1150\,(1.121) = 1289.15 \text{ lb}$$

$$\theta = \tan^{-1}\frac{1289.15}{1190.9} = \tan^{-1} 1.0825 = 47°16'$$

For −10-lb/ft² wind, 0° line angle (30S and 30X towers with negative wind)

$$\theta = \tan^{-1}\frac{-1289.15}{1190.9} = \tan^{-1} -1.0825 = -47°16'$$

For 10-lb/ft² wind, 5° line angle (30X tower with positive wind)

$$2T(\sin a/2) = 2(7821)\,(0.043\,62) = 682.30 \text{ lb}$$

$$\theta = \tan^{-1}\frac{682.30 + 1289.15}{1190.9} = \tan^{-1} 1.6553 = 58°51'$$

For −10-lb/ft² wind, 5° line angle (30A tower with negative wind)

$$\theta = \tan^{-1}\frac{682.30 - 1289.15}{1190.9} = \tan^{-1} -0.509\,32 = -27°00'$$

For 10-lb/ft² wind, 15° line angle (30A tower with positive wind)

$$2T(\sin a/2) = 2\,(7821)\,(0.130\,53) = 2041.75 \text{ lb}$$

$$\theta = \tan^{-1}\frac{2041.75 + 1289.15}{1190.9} = \tan^{-1} 2.7970 = 70°19'$$

The permissible insulator swing angle for the 30S steel tower will be limited by the V-string on the center phase. It is desirable to keep approximately 890 N (200 lb) of extra vertical force on the bottom of the V-string at all times to prevent one leg of the V from becoming slack, which would cause wearing of the metal-to-metal contacts in the string. We use a 100° V-string to permit greater use in this respect. With a 50° insulator swing:

Metric

$$\tan\theta = 1.191\,76 = \frac{5733.13 \text{ N}}{X} \quad \text{(0.48-kPa wind on 350.5 m of conductor)} \quad (X = \text{low point in newtons})$$

Thus, a vertical force of $X = 4810$ N is required to hold the insulator string at a 50° angle when a 0.48-kPa wind is blowing on a sum of adjacent spans equal to 701 m. The conductor required to provide this vertical force plus the extra 890 N is:

4810 – 407 (one-fourth insulator force) = 4403 N
4403 + 890 (extra vertical force on V-string) = 5293 N
5293/20.928 = 252.9 m of conductor

This means the low point for the V-string must be at least 252.9/(2)(350.5) = 0.36, or 36 percent of the sum of adjacent spans. Therefore, for a V-string with a 0.48-kPa wind and 0° line angle,

$$\theta = \tan^{-1} \frac{5733.13}{(350.5)(2)(0.36)(20.928) + 407} = \tan^{-1} 1.007\,87 = 45°13'.$$

U.S. Customary

$$\tan \theta = 1.191\,76 = \frac{1289.15}{X} \quad \begin{array}{l}\text{(10-lb/ft}^2\text{ wind on 1150 ft of conductor)}\\ (X = \text{low point in pounds})\end{array}$$

Thus, a vertical weight of $X = 1082$ lb is required to hold the insulator string at a 50° angle when a 10-lb/ft^2 wind is blowing on a sum of adjacent spans equal to 2300 ft. The conductor required to provide this weight plus the extra 200 lb is:

1082 – 91.5 (one-fourth insulator weight) = 990.5 lb
990.5 + 200 (extra vertical weight on V-string) = 1190.5 lb
1190.5/1.434 = 830.2 ft of conductor

This means the low point for the V-string must be at least 830.2/(2)(1150) = 0.36, or 36 percent of the sum of adjacent spans. Therefore, for a V-string with a 10-lb/ft^2 wind and a 0° line angle,

$$\theta = \tan^{-1} \frac{1289.15}{(1150)(2)(0.36)(1.434) + 91.5} = \tan^{-1} 1.008\,05 = 45°13'.$$

Paragraph 4.

To construct the structure limitation chart for steel structures, proceed:

a. Lay out the axes u[illegible]g the same scale factor for the horizontal scale and the lower part of the vertical scale (see pars. 3.b. and 3.d.). A different scale may be used for the sum of adjacent spans provided the deflection angle bias lines are adjusted accordingly.

b. Calibrate the horizontal axis to the right of the origin in degrees of line angle deflection with the degree calibration equal to the resultant tension at 15.5 °C (60 °F) with 0.48-kPa (10-lb/ft^2) wind pressure on one conductor due to the line deflection angle (par.3.d.).

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c. Calibrate the vertical axis above the origin in meters (feet) for the sum of adjacent spans. The calibrations should be at a distance above the origin equal to the wind pressure at 0.48 kPa (10 lb/ft^2) on a bare conductor of length equal to one-half the sum of adjacent spans (par. 3.e.).

d. Calibrate the vertical axis below the origin in meters (feet) for the distance between low points of the bare (no ice) conductor equal to the vertical force of the conductor. The zero point should be displaced below the origin by a distance equal to one-half the vertical force of the insulator string (pars. 3.b. and 3.c.).

e. With a protractor, lay out the radial angles of insulator swing and draw in heavy boundary lines for the insulator swing limits for each type of structure (par. 3.g.).

f. Lay out the deflection angle bias lines at the computed angle, dependent upon scale factors used for the sum of adjacent spans scale and the distance between low points scale (par. 3.f.). These bias lines are used to automatically add or subtract the wind pressure to or from the resultant tension due to a line deflection angle.

g. Draw in heavy limitation lines (sum of adjacent spans, low-point distance, and line deflection angle) for each type of structure.

h. Add a table to the chart showing steel tower data.

i. List pertinent notes on the chart, including:

- Conductor, size and type
- Conductor loading (NESC light, medium, or heavy, and maximum design wind)
- Conductor maximum tension at full load
- Ruling span
- Number and size of insulators

The structure limitation charts for the example problem on steel structures are shown on figures 55 and 56.

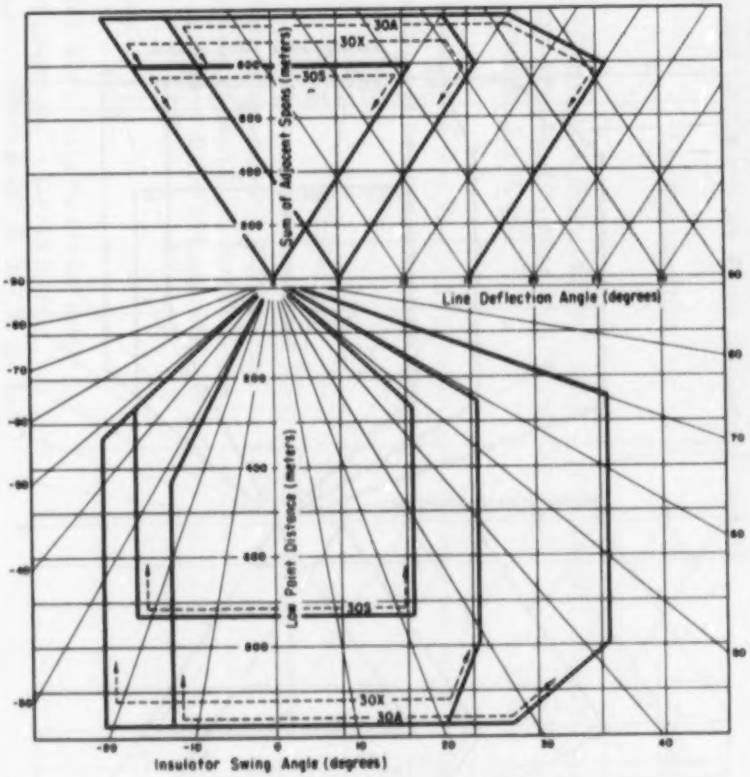
Paragraph 5.

An example problem follows that shows the procedure for obtaining the data required to prepare the wood-pole structure limitation and guying charts.

Example Problem (wood-pole construction)

Assume a 115-kV transmission line with a 242-mm^2 (477-kcmil), ACSR, 24/7 single conductor. Line to be located in an area with a 0.77-kPa (16-lb/ft^2) extreme wind pressure. However, this will not be a factor because the resultant force per unit length of conductor of 18.746 N/m (1.285 lb/ft) for this condition is less than the 27.5345 N/m (1.8867 lb/ft) force for the NESC full-load condition. The following data is also assumed:

Maximum initial conductor tension (NESC heavy) = 33 362 N (7500 lb)
Ruling span = 213.36 m (700 ft)



STRUCTURE DATA

Tower Type	30S	30X	30A	30T	30D
Line Angle	0°	0°-5°	5°-15°	0°-5°	0°-30°
Maximum Single Span (m)					
Minimum Line Angle	396	487.5	487.5	548.5	
Maximum Line Angle	396	396	396	487.5	640
Max. Sum of Adjacent Spans (m)					
Minimum Line Angle	792.5	975.5	975.5	1097	
Maximum Line Angle	792.5	792.5	792.5	975.5	1280
Max. Low Point Distance (m)					
Conductor					
Minimum Line Angle	731.5	975.5	975.5	1280	
Maximum Line Angle	731.5	792.5	792.5	1280	1371.5
Overhead Ground Wire					
Minimum Line Angle	853.5	1036.5	1036.5	1524	
Maximum Line Angle	853.5	853.5	853.5	1524	1463
Maximum Uplift (N)					
Conductor					
Minimum Line Angle				305	
Maximum Line Angle				213.5	305
Overhead Ground Wire					
Minimum Line Angle				396	
Maximum Line Angle				254	396

NOTES

This chart is based on the following:

Conductor size	644 mm², ACSR, 45/7 (bundle of two, 457-mm spacing)
Conductor loading	NESC Heavy, maximum wind of 15.5°C – 0.48 kPa
Conductor tensions	63 165 N maximum per conductor, initial conditions 34 790 N per conductor with 0.48-kPa wind of 15.5°C
Ruling span	350.5 m
Insulators	20 Units (146 by 267 mm)

Figure 55.–Example of a steel structure limitation chart (metric). 104-D-1078.

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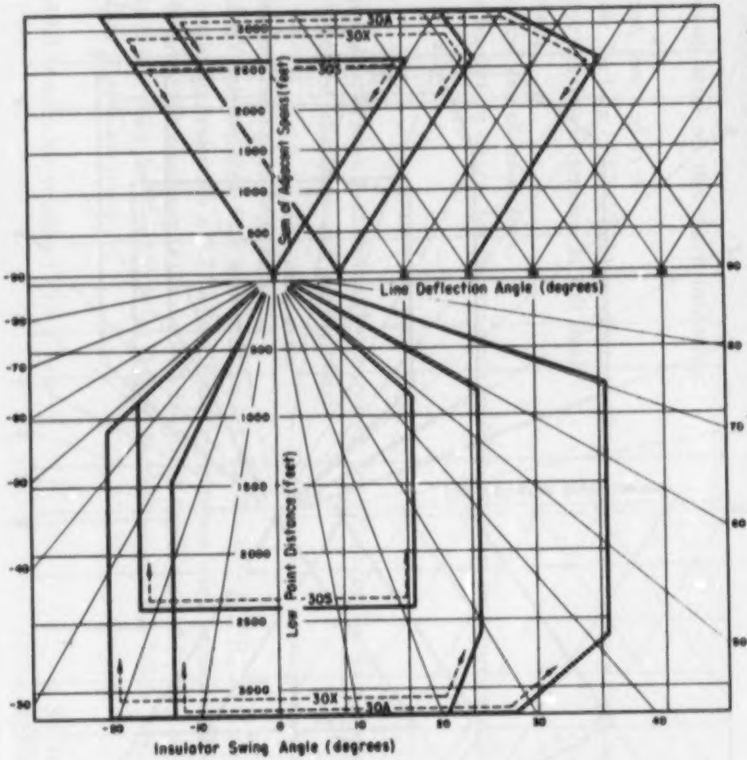

STRUCTURE DATA

Tower Type	30S	30X	30A	30T	30D
Line Angle	0°	0-5°	5-15°	0-5°	0-30°
Maximum Single Span (ft)					
Minimum Line Angle	1300	1600	1600	1800	
Maximum Line Angle	1300	1300	1300	1600	2100
Max. Sum of Adjacent Spans (ft)					
Minimum Line Angle	2600	3200	3200	3600	
Maximum Line Angle	2600	2600	2600	3200	4200
Max. Low Point Distance (ft)					
Conductor					
Minimum Line Angle	2400	3200	3200	4200	
Maximum Line Angle	2400	2600	2600	4200	4500
Overhead Ground Wire					
Minimum Line Angle	2800	3400	3400	5000	
Maximum Line Angle	2800	2800	2800	5000	4800
Maximum Uplift (lb)					
Conductor					
Minimum Line Angle				1000	
Maximum Line Angle				700	1000
Overhead Ground Wire					
Minimum Line Angle				1300	
Maximum Line Angle				833	1300

NOTES

This chart is based on the following:

Conductor size	1272 kcmil, ACSR, 45/7 (bundle of two, 18-in spacing)
Conductor loading	NESC Heavy, maximum wind at 60°F=10 lb/ft^2
Conductor tensions	14 200 lb maximum per conductor, initial conditions 7820 lb. per conductor with 10-lb/ft^2 wind at 60°F
Ruling span	1150 ft.
Insulators	20 Units (5¾ by 10½ in.)

Figure 56.–Example of a steel structure limitation chart (U.S. customary). 104-D-1079.

Seven insulator units per string
146 by 254 mm (5-3/4 by 10 in)
Length per string = 1194 mm (47 in)
Vertical force (weight) per string = 400 N (90 lb)
Wind
Everyday maximum = 0.19 kPa (4 lb/ft²)
Maximum with 13-mm (1/2-in) radial ice = 0.38 kPa (8 lb/ft²)

Design for a minimum low-point distance equal to one-third the sum of adjacent spans.

Wood-pole structure designations and types are:

HS = tangent, suspension
HSB = tangent, suspension, large vertical load
3AC = small line angle, suspension
3A = large line angle, suspension
3AB = large line angle, suspension
3TA = tangent to 90° line angle, dead end

Paragraphs 5.a. through 5.u. describe the procedure for making the calculations required for the charts.

a. Calculate the conductor tensions for the loading conditions shown in the following tabulation. Conductor data and calculations are shown on figures 57 and 58.

Loading condition	*Tension* N	(lb)
13-mm (1/2-in) ice, 0.19-kPa (4-lb/ft²) wind, – 18 °C (0 °F)	33 362	(7500)
No ice, 0.19-kPa (4-lb/ft²) wind, 15.5 °C (60 °F)	11 748	(2641)
No ice, no wind, 15.5 °C (60 °F)	10 872	(2444)

b. Assume a scale to be used for the distance between conductor low points (vertical scale below the point of origin), and compute the scale factor:

Metric
Let
1 mm = 6 m of bare conductor vertical force.
Vertical force of conductor = 8.968 N/m.
Then, 1 mm = (6)(8.968) = 53.808 N, and
1 N = 1/53.808 = 0.018 585 mm (scale factor).

U.S. Customary
Let
1 in = 500 feet of bare conductor weight.
Weight of conductor = 0.6145 lb/ft.
Then, 1 in = (500)(0.6145) = 307.25 lb, and
1 lb = 1/307.25 = 0.003 254 7 in (scale factor).

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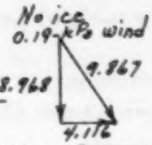
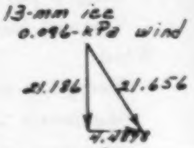
DCm-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**





CONDUCTOR 242 mm² ACSR 24/7
Code Name Flicker
Rated Breaking Strength 76 509 N
Diameter 21.49 mm
Tension Limitations:
Initial, ___ °C, 33⅓ % ______ N
Final, ___ °C, 25 % ______ N
Loaded, ___ °C, 50 % ______ N
Final, 15.5 °C, ___ % ______ N
Computed by ______ Date ______

LOADING Heavy
Linear Force Factor:
Dead Load Force (W') 8.9680 N/m
13 mm Ice (W'') 21.1860 N/m
0.19152 kPa Wind 8.9796 N/m
Resultant: (W''') 27.5345 N/m
Area (A) 273 mm² *K = 4.5241
Temp. Coeff. of Linear Exp.:
0.000 019 44 per °C
* 1977 NESC K = 4.3782

Permanent Set 0.000 490
Creep 0.000 498
Total 0.000 988

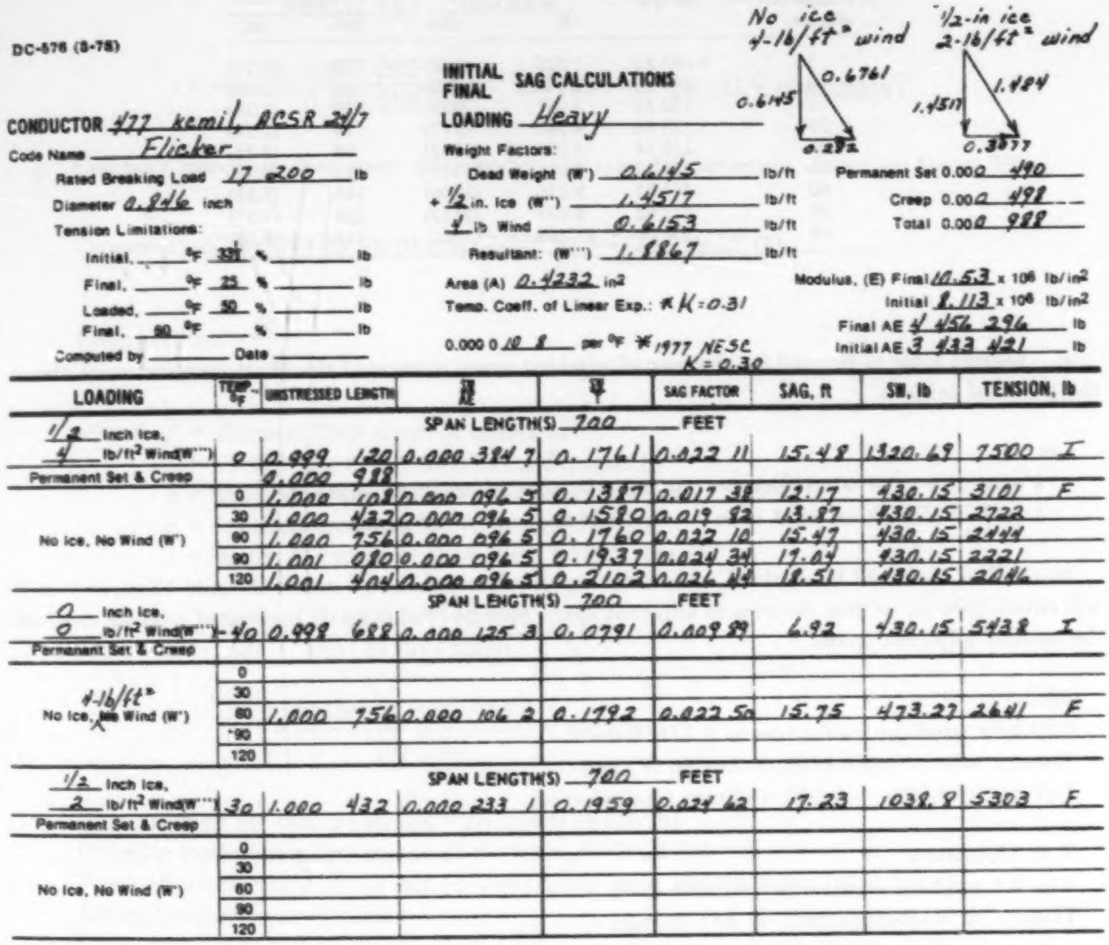
Modulus, (E) Final 72.602 GPa
Initial 55.938 GPa
Final AE 19 820 346 N
Initial AE 15 271 074 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
			SPAN LENGTH(S) 213.36 m					
13 mm Ice 0.19152 kPa Wind (W''')	-18	0.999 120	0.000 384 7	0.1761	0.022 11	4717	5874.76	33 362 I
Permanent Set & Creep		0.000 988						
No Ice, No Wind (W')	-18	1.000 108	0.000 096 5	0.1387	0.017 38	3708	1913.41	13 795 F
	-1	1.000 432	0.000 096 5	0.1580	0.019 82	4229	1913.41	12 110
	15.5	1.000 756	0.000 096 5	0.1760	0.022 10	4715	1913.41	10 872
	32	1.001 080	0.000 096 5	0.1937	0.024 34	5193	1913.41	9 878
	49	1.001 404	0.000 096 5	0.2102	0.026 44	5641	1913.41	9 103
			SPAN LENGTH(S) 213.36 m					
0 mm Ice 0 kPa Wind (W''')	-40	0.998 688	0.000 125 3	0.0791	0.009 89	2110	1913.41	24 190 I
Permanent Set & Creep								
No Ice, ~~No~~ 0.19 kPa Wind (W')	-18							
	-1							
	15.5	1.000 756	0.000 106 2	0.1792	0.02250	4801	2105.22	11 748 F
	32							
	49							
			SPAN LENGTH(S) 213.36 m					
13 mm Ice 0.09576 kPa Wind (W''')	-1	1.000 432	0.000 2331	0.1959	0.024 62	5253	4620.52	23 586 F
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							

Figure 57.–Conductor sag and tension calculation form for example problem on wood-structure limitation chart (metric).

c. Compute the vertical force (weight) of the insulator string and convert one-half the insulator force to millimeters (inches) using the low-point scale factor:

Insulator string force = 400.34 N (90 lb)
One-half insulator string force = 200.17 N (45 lb)
(200.17) (0.018 585) = 3.720 mm or, (45) (0.003 254 7) = 0.1465 in



DC-576 (3-78)

INITIAL
FINAL SAG CALCULATIONS

No ice
4-lb/ft² wind
0.6145
0.6761
0.272

1/2-in ice
2-lb/ft² wind
1.4517
1.484
0.3077

CONDUCTOR 477 kcmil, ACSR 24/7
Code Name Flicker
Rated Breaking Load 17 200 lb
Diameter 0.846 inch
Tension Limitations:
Initial, ___ °F 33 1/3 % ___ lb
Final, ___ °F 25 % ___ lb
Loaded, ___ °F 50 % ___ lb
Final, 60 °F ___ % ___ lb
Computed by ___ Date ___

LOADING Heavy
Weight Factors:
Dead Weight (W') 0.6145 lb/ft
+ 1/2 in. Ice (W'') 1.4517 lb/ft
4 lb Wind 0.6153 lb/ft
Resultant: (W''') 1.8867 lb/ft
Area (A) 0.4232 in²
Temp. Coeff. of Linear Exp.: * K=0.31
0.000 0 10 8 per °F * 1977 NESC K=0.30

Permanent Set 0.000 490
Creep 0.000 498
Total 0.000 988
Modulus, (E) Final 10.53 x 10⁶ lb/in²
Initial 8.113 x 10⁶ lb/in²
Final AE 4 456 296 lb
Initial AE 3 433 421 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb	
				SPAN LENGTH(S) 700 FEET					
1/2 Inch Ice, 4 lb/ft² Wind(W''')	0	0.999 120	0.000 384 7	0.1761	0.022 11	15.48	1320.69	7500	I
Permanent Set & Creep		0.000 988							
No Ice, No Wind (W')	0	1.000 108	0.000 096 5	0.1387	0.017 38	12.17	430.15	3101	F
	30	1.000 432	0.000 096 5	0.1580	0.019 82	13.87	430.15	2722	
	60	1.000 756	0.000 096 5	0.1760	0.022 10	15.47	430.15	2444	
	90	1.001 080	0.000 096 5	0.1937	0.024 34	17.04	430.15	2221	
	120	1.001 404	0.000 096 5	0.2102	0.026 44	18.51	430.15	2046	
				SPAN LENGTH(S) 700 FEET					
0 Inch Ice, 0 lb/ft² Wind(W''')	-40	0.998 688	0.000 125 3	0.0791	0.009 89	6.92	430.15	5438	I
Permanent Set & Creep									
No Ice, ~~No~~ 4-lb/ft² Wind (W')	0								
	30								
	60	1.000 756	0.000 106 2	0.1792	0.022 50	15.75	473.27	2641	F
	90								
	120								
				SPAN LENGTH(S) 700 FEET					
1/2 Inch Ice, 2 lb/ft² Wind(W''')	30	1.000 432	0.000 233 1	0.1959	0.024 62	17.23	1038.8	5303	F
Permanent Set & Creep									
No Ice, No Wind (W')	0								
	30								
	60								
	90								
	120								

Figure 58.–Conductor sag and tension calculation form for example problem on wood-structure limitation chart (U.S. customary).

d. Compute deflection angle scale (horizontal axis to the right of the origin) with the degree calibration equal to the resultant tension at 15.5 °C (60 °F) final with 0.19-kPa (4-lb/ft²) wind pressure, in one conductor due to the line angle:

$$\begin{aligned} F_a &= 2T(\sin \alpha/2) \\ T &= 11\,748 \text{ N } (2641 \text{ lb}) \\ 2T &= 23\,496 \text{ N } (5282 \text{ lb}) \end{aligned}$$

Assume line angles and compute resultant tensions and their scale values. The scale factor must be the same as that computed in paragraph 5.b.

Line angle (α), degrees	Sin $\alpha/2$	$2T(\sin \alpha/2)$		Scale	
		N	(lb)	mm	(in)
5	0.043 62	1 025	(230)	19	(0.75)
10	.087 16	2 048	(460)	38	(1.50)
15	.130 53	3 067	(689)	57	(2.24)
20	.173 65	4 080	(917)	76	(2.99)
25	.216 44	5 085	(1143)	94	(3.72)
30	.258 82	6 081	(1367)	113	(4.45)
40	.342 02	8 036	(1806)	149	(5.88)
50	.422 62	9 930	(2232)	184	(7.27)
60	.500 00	11 748	(2641)	218	(8.60)

e. Assume scale to be used for the sum of adjacent spans portion of the chart (vertical scale above the point of origin):

Let
1 mm = 6 m of wind span = one-half the sum of adjacent spans, or
1 inch = 500 ft of wind span = one-half the sum of adjacent spans.

Note: This scale will be doubled when marking the chart, that is, 1 mm will equal 12 m, or 1 inch will equal 1000 ft, so that the sum of adjacent spans may be read directly instead of reading one-half the sum of adjacent spans.

Metric
0.19-kPa wind on conductor = 4.116 N/m
Then, 1 mm = (6)(4.116) = 24.696 N, and
1 N = 1/24.696 = 0.040 492 mm (scale factor).

U.S. Customary
4-lb/ft^2 wind on conductor = 0.282 lb/ft
Then, 1 in = (500)(0.282) = 141 lb, and
1 lb = 1/141 = 0.007 092 in (scale factor).

f. Calculate angle of bias lines to be drawn right and left of the deflection angle calibrations. These bias lines are used to automatically add or subtract the wind pressure to or from the resultant tension due to a line deflection angle. Because the scale factor used for the deflection angle scale must be the same as that used for the low-point scale, the slope of the bias lines may be determined by

$$\tan \theta = \frac{\text{sum of adjacent spans scale factor}}{\text{low-point scale factor}}$$

where θ is the angle formed by the bias lines with the horizontal axis. The slope of the bias lines will vary depending upon the choice of scale factors previously determined in paragraphs 5.b. and 5.e.

$$\theta = \tan^{-1} \frac{0.040\,492}{0.018\,585} = \tan^{-1} 2.1787 = 65°20' \text{ (metric)}$$

$$\theta = \tan^{-1} \frac{0.007\,092}{0.003\,255} = \tan^{-1} 2.1788 = 65°20' \text{ (U.S. customary)}$$

g. **Compute maximum low-point distance for the type HS structure shown on figure 59:**

Crossarm: 67 by 241 by 7620 mm (2-5/8 by 9-1/2 in by 25 ft)

$$\text{Ultimate load} = \frac{fbd^2}{6L}$$

where: f = ultimate fiber stress of crossarm
= 51 021 kPa (7400 lb/in²) for Douglas fir
b = width of crossarm = 67 mm (2-5/8 in)
d = depth of crossarm = 241 mm (9-1/2 in)
L = length of crossarm projection = 1829 mm (72 in)

$$\frac{fbd^2}{6L} = \frac{(51\,021)\,(67)\,(241)^2}{(6)\,(1829)\,(1000)} = 18\,051 \text{ N or}$$

$$= \frac{(7400)\,(2.625)\,(9.5)^2}{(6)\,(72)} = 4058 \text{ lb}$$

Ultimate load for two crossarms = 36 104 N (8116 lb)
Ultimate load with safety factor of 4 = 9026 N (2029 lb)
Force of conductor with 13-mm (1/2-in) radial ice = 21.186 N/m (1.4517 lb/ft)
Allowable low-point distance:

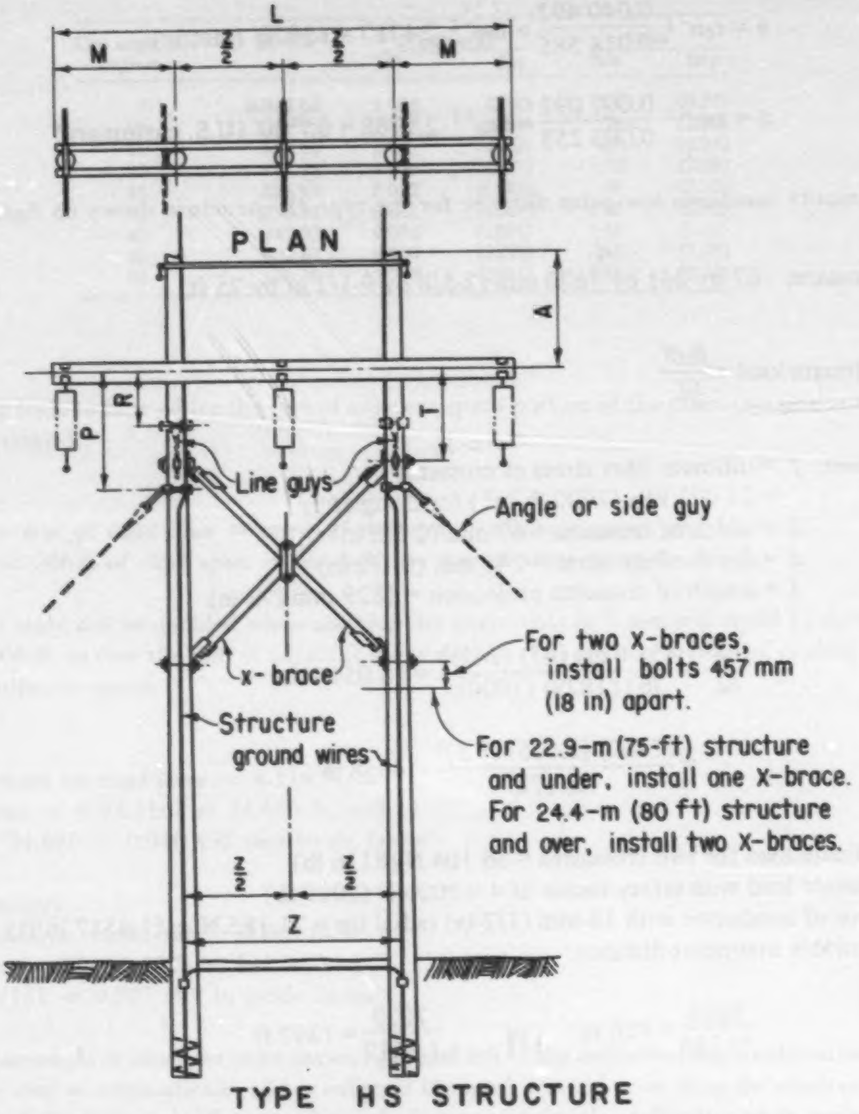
$$\frac{9026}{21.186} = 426 \text{ m} \quad \text{or} \quad \frac{2029}{1.4517} = 1397 \text{ ft}$$

At no load,
force of conductor = 8.968 N/m (0.6145 lb/ft)

$$\text{factor of safety} = \frac{36\,104}{426\,(8.968)} = \frac{8116}{(1397)\,(0.6145)} = 9.45$$

h. **Compute maximum low-point distance for type HSB structure shown on figure 60:**

Using 18 905 N (4250 lb), based on test data, for metal fittings on knee braces at 45° slope:

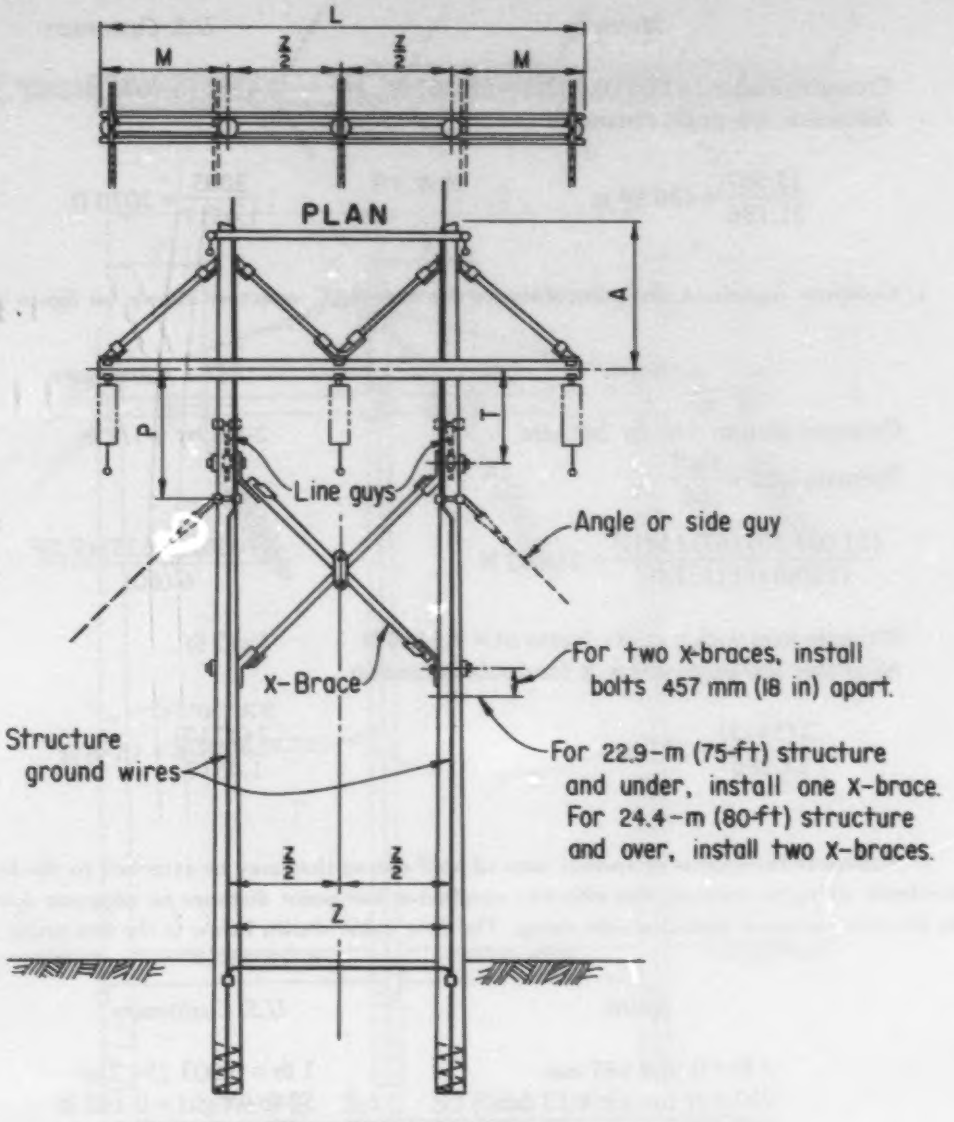

L
M
$\frac{Z}{2}$
$\frac{Z}{2}$
M
PLAN
A
R
P
T
Line guys
Angle or side guy
x- brace
Structure ground wires
$\frac{Z}{2}$
$\frac{Z}{2}$
Z
TYPE HS STRUCTURE

For two X-braces, install bolts 457 mm (18 in) apart.

For 22.9-m (75-ft) structure and under, install one X-brace. For 24.4-m (80 ft) structure and over, install two X-braces.

Voltage, kV	Metric, mm							U.S. Customary, ft-in						
	A	L	Z	M	P	T	R	A	L	Z	M	P	T	R
69	1981	6 401	3048	1676	1219	1524	610	6-6	21-0	10-0	5-6	4-0	5-0	2-0
115	1981	7 620	3658	1981	1829	1524	914	6-6	25-0	12-0	6-6	6-0	5-0	3-0
138	2134	8 839	4267	2286	2743	2438	1219	7-0	29-0	14-0	7-6	9-0	8-0	4-0
161	2438	10 668	5182	2743	2743	2438	1372	8-0	35-0	17-0	9-0	9-0	8-0	4-6

Figure 59.–Type HS wood-pole structure. 104-D-1080.


L
M
Z/2
Z/2
M
PLAN
A
P
T
Line guys
Angle or side guy
X-Brace
For two X-braces, install bolts 457 mm (18 in) apart.
Structure ground wires
For 22.9-m (75-ft) structure and under, install one X-brace. For 24.4-m (80-ft) structure and over, install two X-braces.
Z/2
Z/2
Z

TYPE HSB STRUCTURE

Voltage, kV	Metric, mm						U.S. Customary, ft-in					
	A	L	Z	M	P	T	A	L	Z	M	P	T
69	2490	7 620	3658	1982	1828	1524	8-2	25-0	12-0	6-6	6-0	5-0
115	2490	7 620	3658	1982	1828	1524	8-2	25-0	12-0	6-6	6-0	5-0
138	2134	8 839	4267	2286	2744	1220	7-0	29-0	14-0	7-6	9-0	8-0
161	2439	10 668	5182	2744	2744	1372	8-0	35-0	17-0	9-0	9-0	8-0

Figure 60.–Type HSB wood-pole structure. 104-D-1081.

Metric	*U.S. Customary*
Crossarm load = 18 905 (0.7071) = 13 367 N	4250 (0.7071) = 3005 lb
Allowable low-point distance:	
$\frac{13\,367}{21.186} = 630.94$ m	$\frac{3005}{1.4517} = 2070$ ft

i. Compute maximum low-point distance for type 3AC structure shown on figure 61:

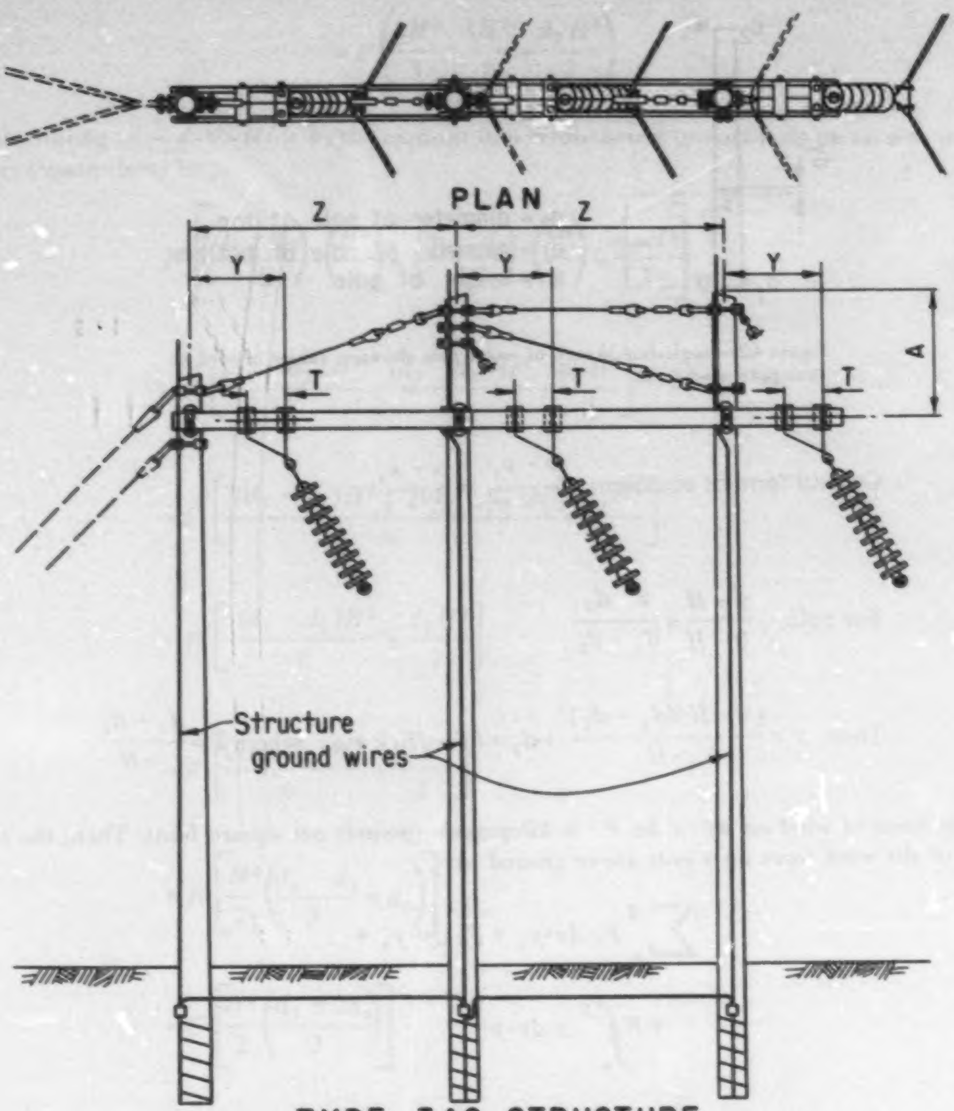
Metric	*U.S. Customary*
Crossarm section = 67 by 241 mm	2-5/8 by 9-1/2 in
Ultimate load = $\frac{fbd^2}{6L}$	
$\frac{(51\,021.52)\,(67)\,(241)^2}{(1000)\,(6)\,(1524)} = 21\,662$ N	$\frac{(7400)\,(2.625)\,(9.5)^2}{6\,(60)} = 4870$ lb
Ultimate load with a safety factor of 4 = 5414 N	1217 lb
Allowable low-point distance for double crossarm:	
$\frac{2\,(5415)}{21.186} = 511$ m	$\frac{2\,(1217)}{1.4517} = 1676$ ft

j. Compute the effects of various sizes of hold downs that may be attached to the bottom of the insulator string to increase the effective conductor low-point distance in adjacent spans, and als to prevent excessive insulator side swing. The first value shown below is the low-point scale factor

Metric	*U.S. Customary*
1 N = 0.018 585 mm	1 lb = 0.003 254 7 in
222.4-N force = 4.13 mm	50-lb weight = 0.163 in
444.8-N force = 8.27 mm	100-lb weight = 0.325 in
667.2-N force = 12.40 mm	150-lb weight = 0.488 in

k. Compute the maximum allowable sum of adjacent spans on a type HS structure (fig. 59) b determining the wind loading on the structure:

Assume 18 288-mm (60-ft), class 2 western red cedar poles (western red cedar data are used fo this example because this is the lowest strength wood permitted by USBR specifications). Th different classes of poles are a function of the pole circumference, see table B-3 in appendix B. Th formula for computing the wind force on a pole may be derived using figure 62:


PLAN
Z
Z
Y
Y
Y
T
T
T
A
Structure ground wires

TYPE 3AC STRUCTURE

Voltage, kV	Metric, mm				U.S. Customary, ft-in			
	A	Z	Y	T	A	Z	Y	T
69	1982	3658	1372	343	6-6	14-0	4-6	1-1½
115	1982	4267	1524	610	6-6	14-0	5-0	2-0
138	2591	5487	2058	610	8-6	18-0	6-9	2-0
161	2591	5487	2058	610	8-6	18-0	6-9	2-0

Figure 61.–Type 3AC wood-pole structure. 104-D-1082.

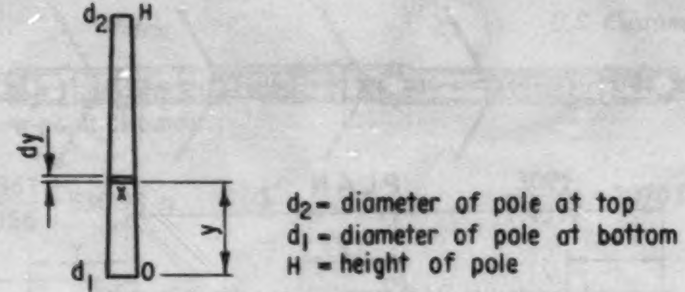

d2
H
dy
x
y
d1
0
d2 - diameter of pole at top
d1 - diameter of pole at bottom
H - height of pole

Figure 62.–Single-line sketch of wood pole showing values needed to compute wind force.

General form of equation: $\dfrac{y - y_1}{y_2 - y_1} = \dfrac{x - x_1}{x_2 - x_1}$

For pole, $\dfrac{y - H}{0 - H} = \dfrac{x - d_2}{d_1 - d_2}$

Then, $x = \dfrac{(y - H)(d_1 - d_2)}{-H} + d_2 = (y - H)k + d_2$, where $k = \dfrac{d_1 - d_2}{-H}$

Let the force of wind on $dy \cdot x$ be F in kilopascals (pounds per square foot). Then, the total moment of the wind force on a pole above ground is:

$$\sum_0^H Fx\, dy \cdot y_1 + Fx\, dy \cdot y_2 + \dots$$

$$= F\int_0^H x\, dy \cdot y$$

$$= F\int_0^H y[(y - H)k + d_2]dy$$

$$= F\int_0^H (ky^2 - kHy + d_2 y)dy$$

$$= F\left[\frac{ky^3}{3} - \frac{kHy^2}{2} + \frac{d_2 y^2}{2}\right]_0^H$$

$$= F\left(\frac{kH^3}{3} - \frac{kH^3}{2} + \frac{d_2 H^2}{2}\right)$$

Substituting $(d_1 - d_2)/-H$ for k, the moment in newton-meters (pound-feet) on an area in square meters (square feet) is:

$$F\left[\left(\frac{d_1 - d_2}{-H}\right)\left(\frac{H^3}{3}\right) - \left(\frac{d_1 - d_2}{-H}\right)\left(\frac{H^3}{2}\right) + \frac{d_2 H^2}{2}\right]$$

$$= F\left[\frac{(d_1 - d_2)H^2}{-3} + \frac{(d_1 - d_2)H^2}{2} + \frac{d_2 H^2}{2}\right]$$

$$= F\left[\frac{2(d_1 - d_2)H^2 - 3(d_1 - d_2)H^2}{-6} + \frac{d_2 H^2}{2}\right]$$

$$= F\left[\frac{-(d_1 - d_2)H^2}{-6} + \frac{d_2 H^2}{2}\right]$$

$$= F\left[\frac{(d_1 - d_2)H^2}{6} + \frac{d_2 H^2}{2}\right]$$

$$= F\left[\frac{H^2}{2}\left(\frac{d_1 - d_2}{3} + d_2\right)\right]$$

$$= F\left[\frac{H^2}{2}\left(\frac{d_1 + 2d_2}{3}\right)\right]$$

$= \dfrac{FH^2(d_1 + 2d_2)}{6}$ in lb·ft if diameters are in feet, or

$= \dfrac{FH^2(d_1 + 2d_2)}{6000}$ in N·m if diameters are in millimeters, or

$= \dfrac{FH^2(d_1 + 2d_2)}{72}$ in lb·ft if diameters are in inches.

Metric

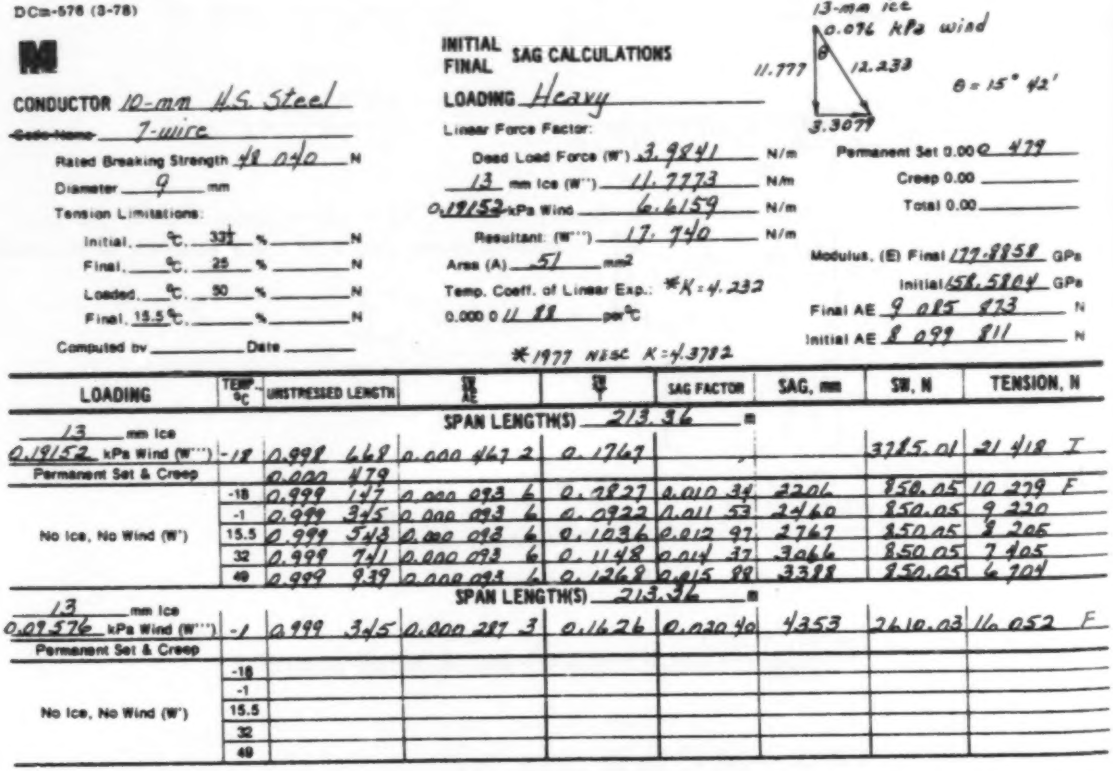
$$M_p = \frac{FH^2(d_1 + 2d_2)}{6000}, \text{where } M_p = \text{moment}$$

$$M_p = \frac{(0.383\,04)\,(1000)\,(15.850)^2\ [404.34 + 2\,(202.18)]}{6000} = 12\,970\ \text{N}\cdot\text{m}$$

U.S. Customary

$$M_p = \frac{FH^2(d_1 + 2d_2)}{72} = \frac{8\,(52)^2\ [15.92 + 2\,(7.96)]}{72} = 9566\ \text{lb}\cdot\text{ft}$$

The maximum allowable SAS (sum of adjacent spans) *L* can now be found by statics. Assume two 10-mm (3/8-in) high strength steel, 7-strand overhead ground wires with a maximum full-load tension of 21 418-N (4815-lb) initial condition. Sag and tension calculations for the ground wire are shown on figures 63 and 64.



DC≡-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

13-mm ice
0.076 kPa wind
11.777
12.233
3.3077
θ
θ = 15° 42'

CONDUCTOR 10-mm H.S. Steel
~~Code Name~~ 7-wire
Rated Breaking Strength 48 040 N
Diameter 9 mm
Tension Limitations:
Initial, ___ °C, 33⅓ % ______ N
Final, ___ °C, 25 % ______ N
Loaded, ___ °C, 50 % ______ N
Final, 15.5 °C, ___ % ______ N
Computed by ______ Date ______

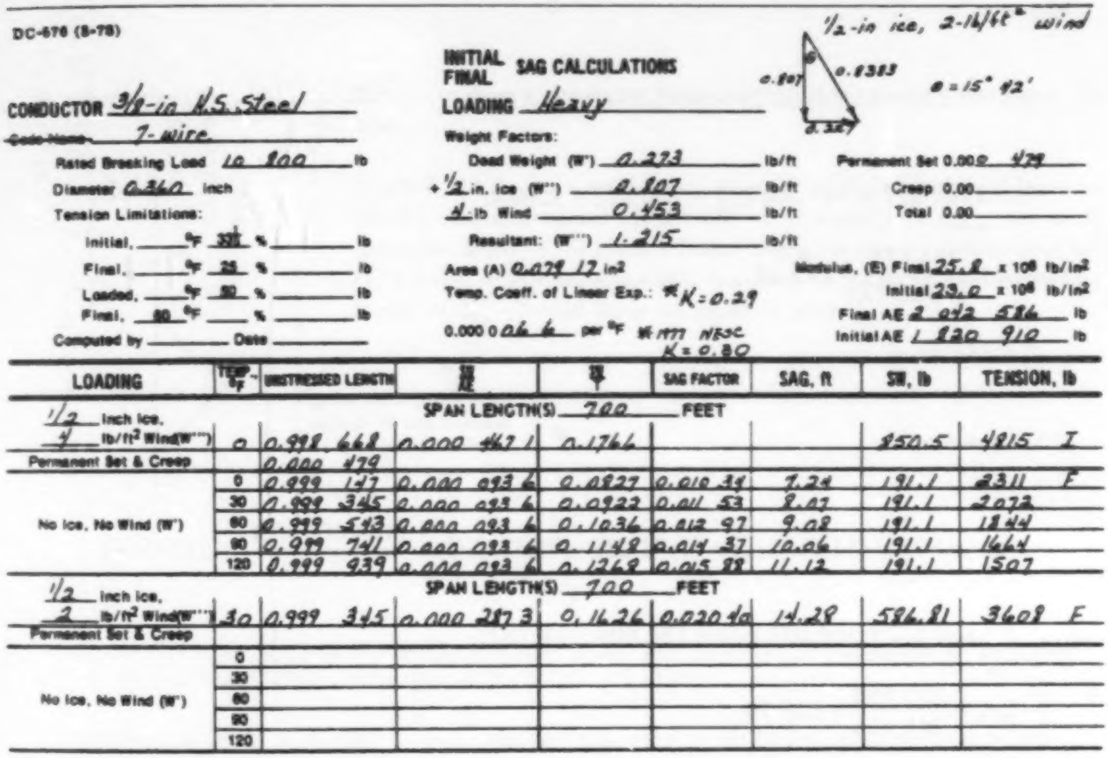
LOADING Heavy
Linear Force Factor:
Dead Load Force (W') 3.9841 N/m
13 mm Ice (W'') 11.7773 N/m
0.19152 kPa Wind 6.6159 N/m
Resultant: (W''') 17.740 N/m
Area (A) 51 mm2
Temp. Coeff. of Linear Exp.: *K = 4.232
0.000 0 11 88 per °C

*1977 NESC K = 4.3782

Permanent Set 0.000 479
Creep 0.00 ______
Total 0.00 ______
Modulus, (E) Final 177.8858 GPa
Initial 158.5804 GPa
Final AE 9 085 873 N
Initial AE 8 099 811 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
SPAN LENGTH(S) 213.36 m								
13 mm Ice 0.19152 kPa Wind (W''')	-18	0.998 668	0.000 467 2	0.1767			3785.01	21 418 I
Permanent Set & Creep		0.000 479						
No Ice, No Wind (W')	-18	0.999 147	0.000 093 6	0.0827	0.010 34	2206	850.05	10 279 F
	-1	0.999 345	0.000 093 6	0.0922	0.011 53	2460	850.05	9 220
	15.5	0.999 543	0.000 093 6	0.1036	0.012 97	2767	850.05	8 205
	32	0.999 741	0.000 093 6	0.1148	0.014 37	3066	850.05	7 405
	49	0.999 939	0.000 093 6	0.1268	0.015 88	3388	850.05	6 704
SPAN LENGTH(S) 213.36 m								
13 mm Ice 0.09576 kPa Wind (W''')	-1	0.999 345	0.000 287 3	0.1626	0.020 40	4353	2610.03	16 052 F
Permanent Set & Creep								
No Ice, No Wind (W')	-18							
	-1							
	15.5							
	32							
	49							

Figure 63.–Overhead ground wire sag and tension calculation form for example problem on wood-structure limitation chart (metric).



DC-676 (8-78)

INITIAL
FINAL SAG CALCULATIONS

½-in ice, 2-lb/ft² wind

0.807
0.8383
0.227
θ

θ = 15° 42'

CONDUCTOR 3/8-in H.S. Steel
~~Code Name~~ 7-wire
Rated Breaking Load 10 800 lb
Diameter 0.360 inch
Tension Limitations:
Initial, ____ °F 33⅓ % ____ lb
Final, ____ °F 25 % ____ lb
Loaded, ____ °F 50 % ____ lb
Final, 60 °F ____ % ____ lb
Computed by ____ Date ____

LOADING Heavy
Weight Factors:
Dead Weight (W') 0.273 lb/ft
+ ½ in. Ice (W'') 0.807 lb/ft
4 lb Wind 0.453 lb/ft
Resultant: (W''') 1.215 lb/ft
Area (A) 0.079 17 in²
Temp. Coeff. of Linear Exp.: *K = 0.29
0.000 0 06 6 per °F *1977 NESC K = 0.30

Permanent Set 0.000 479
Creep 0.00____
Total 0.00____
Modulus, (E) Final 25.8 x 10⁶ lb/in²
Initial 23.0 x 10⁶ lb/in²
Final AE 2 042 586 lb
Initial AE 1 820 910 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
			SPAN LENGTH(S) 700 FEET					
½ Inch Ice, 4 lb/ft² Wind (W''')	0	0.998 668	0.000 467 1	0.1766			850.5	4815 I
Permanent Set & Creep		0.000 479						
No Ice, No Wind (W')	0	0.999 147	0.000 093 6	0.0827	0.010 34	7.24	191.1	2311 F
	30	0.999 345	0.000 093 6	0.0922	0.011 53	8.07	191.1	2072
	60	0.999 543	0.000 093 6	0.1036	0.012 97	9.08	191.1	1844
	90	0.999 741	0.000 093 6	0.1148	0.014 37	10.06	191.1	1664
	120	0.999 939	0.000 093 6	0.1268	0.015 88	11.12	191.1	1507
			SPAN LENGTH(S) 700 FEET					
½ Inch Ice, 2 lb/ft² Wind (W''')	30	0.999 345	0.000 287 3	0.1626	0.020 40	14.28	586.81	3608 F
Permanent Set & Creep								
No Ice, No Wind (W')	0							
	30							
	60							
	90							
	120							

Figure 64.–Overhead ground wire sag and tension calculation form for example problem on wood-structure limitation chart (U.S. customary).

Using the sketch shown on figure 65, and taking moments about the base:

(2 OGW) (wind force on iced OGW) (moment arm) (1/2 SAS) + (3 cond.) (wind force on iced cond.) (moment arm) (1/2 SAS) = [(max. allowable moment on pole) (2 poles)/(safety factor of 2)] – [(wind force on pole) (2 poles)]

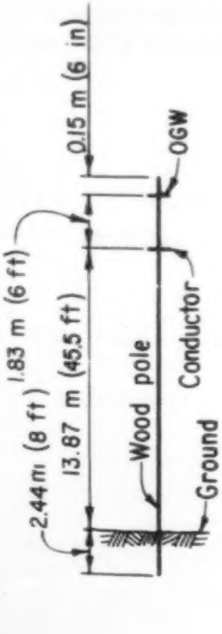


Figure 65.–Single-line sketch of one pole of a type HS wood-pole structure.

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Metric

$$(2)\,(13.222)\,(15.70)\,(L/2) + (3)\,(17.96)\,(13.87)\,(L/2) = \frac{(250\;555)\,(2)}{2} - (2)\,(12\;970)$$

$$415.1708\,L/2 + 747.208\,L/2 = 250\;555 - 25\;940$$

$$L/2 = \frac{224\;615}{1162.379} = 193.24$$

$$L = 386.48\text{ m}$$

U.S. Customary

$$(2)\,(0.9066)\,(51.5)\,(L/2) + (3)\,(1.231)\,(45.5)\,(L/2) = \frac{(184\;800)\,(2)}{2} - (2)\,(9566)$$

$$93.380\,L/2 + 168.031\,L/2 = 184\;800 - 19\;132$$

$$L/2 = \frac{165\;668}{261.411} = 633.74$$

$$L = 1267\text{ ft}$$

1. Compute the allowable maximum sum of adjacent spans on a type HS structure with X-brace (fig. 59) for various line angles:

Metric

$$\frac{FH^2(d_1 + 2d_2)}{6000} = \frac{(0.383\;04)\,(1000)\,(3.51)^2\;[246.63 + 2(202.18)]}{6000} = 512.01\text{ N}\cdot\text{m}$$

U.S. Customary

$$\frac{FH^2(d_1 + 2d_2)}{72} = \frac{(8)\,(11.5)^2\;[9.71 + 2(7.96)]}{72} = 376.6\text{ lb}\cdot\text{ft}$$

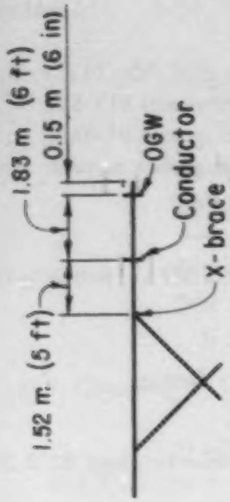


Figure 66.–Single-line sketch of top portion of a type HS wood-pole structure with X-brace.

Using the sketch shown on figure 66, and taking moments about the base:

(2 OGW) (2 $T_{max.}$ sin $\alpha/2$) (moment arm) + (2 OGW) (wind force on OGW) (moment arm) (1/2 SAS) + (3 cond.) (2 $T_{max.}$ sin $\alpha/2$) (moment arm) + (3 cond.) (wind force on cond.) (moment arm) (1/2 SAS) = [(max. allowable moment on pole) (2 poles)/(safety factor of 2)] – [(wind force on pole) (2 poles)]

Metric

$$(2)\ (42\,836)\ (\sin \alpha/2)\ (3.35) + (2)\ (13.222)\ (3.35)\ (L/2) + (3)\ (66\,724)\ (\sin \alpha/2)\ (1.52) + (3)\ (17.96)(1.52)(L/2) = (56\,870)\ (2)/2 - (2)\ (512)$$

$$287\,001\ (\sin \alpha/2) + 88.587\ L/2 + 305\,062\ (\sin \alpha/2) + 82.113\ L/2 = 56\,870 - 1021$$
$$592\,063\ (\sin \alpha/2) + 170.700\ L/2 = 55\,849$$
$$592\,063\ (\sin \alpha/2) + 85.35\ L = 55\,849$$
$$6936.88\ (\sin \alpha/2) + L = 654.35$$

Assume values for L and solve for α:

L, m	sin $\alpha/2$	$\alpha/2$	α
654.35	0	0	0
300	0.051 08	2°55′	5°50′
0	0.094 33	5°24′	10°48′

A line representing these tabulated values should be drawn on the sum of adjacent spans chart.

U.S. Customary

$$(2)\ (9630)\ (\sin \alpha/2)\ (11) + (2)\ (0.9066)\ (11)\ (L/2) + (3)\ (15\,000)\ (\sin \alpha/2)\ (5) + (3)\ (1.231)\ (5)\ (L/2) = (41\,945)\ (2)/2 - (2)\ (376.6)$$

$$22\,747.2\ (\sin \alpha/2) + L = 2144.86$$

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2144.86	0	0	0
1000	0.050 33	2°53′	5°46′
0	0.094 29	5°24′	10°48′

Assuming a working fiber stress, at 15.5 °C (60 °F) with no wind load, of 6.895 MPa (1000 lb/in²) for western red cedar:

$$\frac{\text{ultimate fiber stress}}{\text{working stress}} = \frac{38.612 \text{ MPa}}{6.895 \text{ MPa}} \text{ or } \left(\frac{5600 \text{ lb/in}^2}{1000 \text{ lb/in}^2}\right) = 5.6 \text{ safety factor}$$

With a 15.5 °C (60 °F) no wind tension of 10 872 N (2444 lb) on the conductor, and 8205 N (1844 lb) on the overhead ground wire, the moment equation would be:

(2 OGW) ($2T \sin \alpha/2$) (moment arm) + (3 cond.) ($2T \sin \alpha/2$) (moment arm) = (max. allowable moment on wood pole) (2 poles)/(safety factor of 5.6)

Metric

$(2)\ (16\ 410)\ (\sin \alpha/2)\ (3.35) + (3)\ (21\ 744)\ (\sin \alpha/2)\ (1.524) = (56\ 870)\ (2)/5.6$
$109\ 947\ (\sin \alpha/2) + 99\ 413.57\ (\sin \alpha/2) = 20\ 310.71$
$209\ 360.57\ (\sin \alpha/2) = 20\ 310.71$
$\sin \alpha/2 = 0.097\ 01,\ \alpha/2 = 5°34'$
$\alpha = 11°08'$

U.S. Customary

$(2)\ (3688)\ (\sin \alpha/2)\ (11) + (3)\ (4888)\ (\sin \alpha/2)\ (5) = (41\ 945)\ (2)/5.6$
$\sin \alpha/2 = 0.096\ 99,\ \alpha/2 = 5°34'$
$\alpha = 11°08'$

If this angle had been less than the largest angle computed previously, then a vertical line would be drawn on the sum of adjacent spans chart at 11°08′ from 0 to the intersection with the line drawn using the previously tabulated angles. This means that the original line would be cut off at 11°08′.

m. Compute the allowable sum of adjacent spans due to bolt shear on a type 3AC structure (fig. 61) for various line angles. Assume conductor on inside of angle is guyed to top of middle pole, and the two outside conductors are guyed from pole on outside of angle.

***Example*: without shear plates**

(2 cond.) ($2T_{\text{max.}} \sin \alpha/2$) + (2 cond.) (wind force on iced cond.) (1/2 SAS) = (allowable bolt shear)

Metric

(2) (2) (33 362) (sin $\alpha/2$) + (2) (17.959) ($L/2$) = (10 831.37) (0.75)*
133 448 (sin $\alpha/2$) + 17.959 L = 8123.53
7430.70 (sin $\alpha/2$) + L = 452.34
Assume values for L and solve for α:

L, m	sin $\alpha/2$	$\alpha/2$	α
452.34	0	0	0
200	0.033 96	1°56′	3°52′
0	0.060 87	3°29′	6°58′

U.S. Customary

(2) (2) (7500) (sin $\alpha/2$) + (2) (1.2306) ($L/2$) = (2435) (0.75)*
24 378.35 (sin $\alpha/2$) + L = 1507.92
Assume values for L and solve for α:

L, ft	sin $\alpha/2$	$\alpha/2$	α
1507.92	0	0	0
1000	0.020 83	1°11′	2°22′
0	0.061 85	3°32′	7°04′

Example : with shear plates

Metric

133 448 (sin $\alpha/2$) + 17.959 L = 26 689.2**
7430.70 (sin $\alpha/2$) + L = 1486.12
Assume values for L and solve for α:

L, m	sin $\alpha/2$	$\alpha/2$	α
450	0.139 44	8°01′	16°02′
225	.169 72	9°46′	19°32′
0	.199 99	11°32′	23°04′

---

* and ** Data from National Design Specifications for Stress-Grade Lumber and Its Fastenings, 1973 Edition, National Forest Products Association, Washington D.C.

* Part VI Bolted Joints:

Paragraph 600-K-3.–The tabulated loads (table 12 for double shear) shall be used for a main member which is twice the thickness of the thinnest side members (2-5/8 in x 2 = 5-1/4 in). Permissible load = 2435 lb = 10 831.37 N.

Paragraph 600-G-2.–When joints are to be exposed to weather, .75 percent of the tabulated loads apply.

** Part V Timber Connector Joints:

Paragraph 500-B-2.–An assembly with two connector units of the same size used in contact faces with the connectors concentric with the same bolt axis, the total allowable connector load shall be the sum of the allowable connector loads given for each connector unit used (table 9).

U.S. Customary

$30\,000 (\sin \alpha/2) + 1.2306\ L = 6000^{**}$
$24\,378.35 (\sin \alpha/2) + L = 4875.67$
Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.117 96	6°46′	13°32′
1000	.158 98	9°09′	18°18′
0	.200 25	11°33′	23°06′

To be practical, assume the same maximum sum of adjacent spans (upper limit) for type 3AC as for type HS structure.

n. Compute strength limitation of single insulator string used on angle structures:

Full load conductor tension = 33 362 N (7500 lb)
Find $2T(\sin \alpha/2)$ for a 60° line angle:

$$2T \sin 30^\circ = 2(33\,362)\,(0.5) = 33\,362 \text{ N, or}$$
$$= 2(7500)\,(0.5) = 7500 \text{ lb}$$

A 60° line angle on chart (as computed under par. 5.d.) = 218 mm (8.6 in)

$$\text{Then, } 1 \text{ N} = \frac{218}{33\,362} = 0.006\,544\,6 \text{ mm} \quad \left(1 \text{ lb} = \frac{8.6}{7500} = 0.001\,146\,7 \text{ in}\right)$$

Using a safety factor of 2.5 on 88 964-N (20 000-lb) insulator units gives a working maximum of 35 585 N (8000 lb). Force of iced conductor = 21.186 N/m (1.4517 lb/ft).

Let H be the horizontal force due to the line angle, and V be the conductor force between low points in adjacent spans.

Then,

$$H^2 + V^2 = (35\,585 \text{ N})^2 \text{ or } (8000 \text{ lb})^2$$

$$H(\text{N}) = \sqrt{(35\,585)^2 - V^2} \quad \text{or} \quad H(\text{lb}) = \sqrt{(8000)^2 - V^2}$$

Solve for *H* by assuming low-point distances:

Metric

Low point, m	V, N	V^2	H, N	mm
0	0	0	35 585	233
200	4 237.2	17 953 864	35 332	231
400	8 474.4	71 815 455	34 561	226
600	12 711.4	161 584 775	33 237	218
800	16 948.8	287 261 821	31 289	205
1000	21 186.0	448 846 596	28 591	187

U.S. Customary

Low point, ft	V, lb	V^2	H, lb	in
0	0	0	8000	9.17
500	725.85	526 858	7967	9.14
1000	1451.70	2 107 433	7867	9.02
1500	2177.55	4 741 724	7698	8.83
2000	2903.40	8 429 732	7455	8.55
2500	3629.25	13 171 456	7129	8.17
3000	4355.10	18 966 896	6711	7.70

Since angle structures with suspension insulators are limited to a maximum line angle of 60°, the preceding limitation will not have much bearing. To show the effect of such calculations, assume 66 723-N (15 000-lb) insulator units are to be considered. Then, with a 2.5 safety factor, we would have a working tension of 26 689 N (6000 lb) and,

$$H(\mathrm{N}) = \sqrt{(26\,689)^2 - V^2} \quad \text{or} \quad H(\mathrm{lb}) = \sqrt{(6000)^2 - V^2}$$

Solve for *H* by assuming low-point distances:

Metric

Low point, m	V, N	V^2	H, N	mm
0	0	0	26 689	175
200	4 237.2	17 953 864	26 350	172
400	8 474.4	71 815 455	25 308	166
600	12 711.6	161 584 775	23 467	154
800	16 948.8	287 261 821	20 617	135
1000	21 186.0	448 846 596	16 231	106

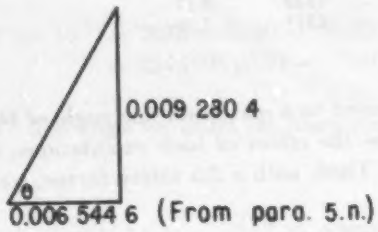
U.S. Customary

Low point, ft	*V*, lb	V^2	*H*, lb	in
0	0	0	6000	6.88
500	725.85	526 858	5956	6.83
1000	1451.70	2 107 433	5822	6.68
1500	2177.55	4 741 724	5591	6.41
2000	2903.25	8 429 732	5251	6.02
2500	3629.25	13 171 456	4778	5.48
3000	4355.10	18 966 896	4127	4.73

o. Determine angle of bias lines to be drawn on the sum of adjacent spans chart for reading the limitation of single insulator strings under various combinations of loadings:

Metric

Sum of adjacent spans scale, 1 mm = 6 m (from par. 5.e.)
For SAS = 600 m, wind span = 1/2 SAS = 300 m, 300/6 = 50 mm on chart
Conductor with 13-mm ice and 0.38-kPa wind, wind force = 17.959 N/m
The wind load on 300 m of iced conductor = (300) (17.959) = 5387.7 N
1 N = 50/5387.7 = 0.009 280 4 mm



From figure 67,

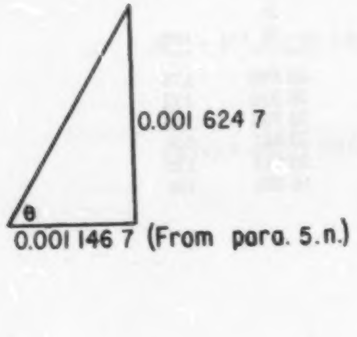
$$\tan\theta = \frac{0.009\ 280\ 4}{0.006\ 544\ 6} = 1.418\ 02$$

$$\theta = 54°48'$$

Figure 67.–Force triangle showing angle of bias lines for wood-structure limitation chart (metric).

U.S. Customary

Sum of adjacent spans scale, 1 in = 500 ft (from par. 5.e.)
For SAS = 2000 ft, wind span = 1/2 SAS = 1000 ft, 1000/500 = 2 in on chart
Conductor with 1/2-in ice and 8-lb wind, wind force = 1.231 lb/ft
The wind load on 1000 ft of iced conductor = (1000) (1.231) = 1231 lb
1 lb = 2/1231 = 0.001 624 7 in



From figure 68,

$$\tan\theta = \frac{0.001\ 624\ 7}{0.001\ 146\ 7} = 1.416\ 85$$

$$\theta = 54°48'$$

Figure 68.–Force triangle showing angle of bias lines for wood-structure limitation chart (U.S. customary).

p. Compute conductor guying for H-frame type structures with no guys on the overhead ground wires:

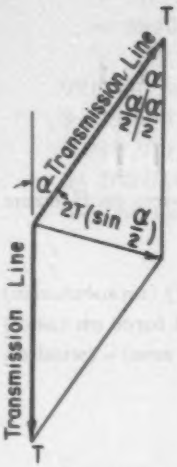


Figure 69.–Force triangle showing resultant conductor force due to line angle.

When a transmission line changes direction, there is a horizontal force created which must be considered in all design work. If the line tension is the same on each side of the angle structure, the resultant force will be on the split of the angle formed by the two legs of the transmission line. The value of the resultant force is $2T(\sin \alpha/2)$, see figure 69. For guying, we also must consider a force that is the result of wind blowing on the conductor. We assume that the wind blows perpendicular to both spans of the transmission line. This is highly improbable, but it is the worst case that could happen. This assumption will usually add to the safety factor. We also use more practical values for wind pressure, 0.38 kPa (8 lb/ft^2) for NESC heavy and medium loading areas and 0.57 kPa (12 lb/ft^2) for NESC light loading areas, instead of the values called for in NESC rule 250.B.: 0.19 kPa (4 lb/ft^2) for NESC heavy and medium loading areas and 0.43 kPa (9 lb/ft^2) in NESC light loading areas. Where extreme wind loading on the line (rule 250.C.) is greater than the combined ice and wind load (or wind load alone) prescribed in rule 250.B., then the proper values taken from the wind pressure map (fig. 250-2 of NESC) should be used for all structure and guy loading computations.

***Example*:**

$$H = 2T(\sin \alpha/2) + (\text{wind force})\,(L/2)$$

Metric

$$H = 2(33\ 362)(\sin \alpha/2) + \left[\left(\frac{47}{1000}\right)(0.383\ 04)(1000)\right] L/2$$

$$= 66\ 724\,(\sin \alpha/2) + 17.961\,(L/2)$$

$$= 66\ 724\,(\sin \alpha/2) + 8.98\,L$$

U.S. Customary

$$H = 2(7500)(\sin \alpha/2) + \left[\left(\frac{1.846}{12}\right)(8)\right] L/2$$

$$= 15\ 000\,(\sin \alpha/2) + 0.6155\,L$$

Using 11-mm (7/16-in), 7-wire, high-strength steel guy wire with a breaking strength of 64 500 N (14 500 lb), a safety factor of 2.67, and set at an angle of 45° to the pole:

Metric

$$\frac{64\,500}{2.67}(0.7071) = 17\,080 \text{ N of horizontal pull per guy wire}$$

U.S. Customary

$$\frac{14\,500}{2.67}(0.7071) = 3840 \text{ lb of horizontal pull per guy wire}$$

Then, guying of the horizontal forces of the conductors and overhead ground wires on H-frame structures is determined by the moment equation:

(2 OGW) (2 $T_{\text{max.}}$ sin $\alpha/2$) (moment arm) + (2 OGW) (wind force on OGW) (moment arm) (1/2 SAS) + (3 cond.) (2 $T_{\text{max.}}$ sin $\alpha/2$) (moment arm) + (3 cond.) (wind force on cond.) (moment arm) (1/2 SAS) = (allowable horizontal load on guy) (moment arm) – (wind on poles)

***Metric* – For one guy:**

$$(2)\,(2)\,(21\,418)\,(\sin \alpha/2)\,(15.697) + (2)\,(13.231)\,(15.697)\,(L/2) + (3)\,(2)\,(33\,362)\,(\sin \alpha/2)\,(13.868) + (3)\,(17.961)\,(13.868)\,(L/2) = (17\,080)\,(12.040) - 25\,939.51$$

$$1\,344\,793.38\,(\sin \alpha/2) + 415.48\;L/2 + 2\,775\,985.30\,(\sin \alpha/2) + 747.249\;L/2 = 179\,703.69$$

$$4\,120\,778.68\,(\sin \alpha/2) + 1162.729\;L/2 = 179\,703.69$$
$$4\,120\,778.68\,(\sin \alpha/2) + 581.364\;L = 179\,703.69$$
$$7088.12\,(\sin \alpha/2) + L = 309.107$$

Assume values for L and solve for α:

L, m	sin $\alpha/2$	$\alpha/2$	α
309.107	0	0	0
150	0.022 45	1°17′	2°34′
0	.043 61	2°30′	5°00′

For two guys:

$$4\,120\,778.68\,(\sin \alpha/2) + 581.364\;L = (2)\,(17\,080)\,(12.040) - 25\,939.51 = 385\,346.89$$
$$7088.12\,(\sin \alpha/2) + L = 662.832$$

Assume values for L and solve for α:

L, m	sin $\alpha/2$	$\alpha/2$	α
662.83	0	0	0
300	0.046 96	2°41′	5°22′
0	.093 51	5°22′	10°44′

U.S. Customary **–For one guy:**

$$(2)\ (2)\ (4815)\ (\sin \alpha/2)\ (51.5) + (2)\ (0.906)\ (51.5)\ (L/2)$$
$$+ (3)\ (2)\ (7500)\ (\sin \alpha/2)\ (45.5) + (3)\ (1.231)\ (45.5)\ (L/2)$$
$$= 3840\ (39.5) - 19\ 132$$

$991\ 890\ (\sin \alpha/2) + 93.318\ L/2 + 2\ 047\ 500\ (\sin \alpha/2) + 168.032\ L/2 = 132\ 548$

$3\ 039\ 390\ (\sin \alpha/2) + 261.35\ L/2 = 132\ 548$

$3\ 039\ 390\ (\sin \alpha/2) + 130.67\ L = 132\ 548$

$23\ 260.044\ (\sin \alpha/2) + L = 1014.372$

Assume values for *L* and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
1014.372	0	0	0
500	0.022 11	1°16′	2°32′
0	.043 61	2°30′	5°00′

For two guys:

$3\ 039\ 390\ (\sin \alpha/2) + 130.67\ L = (2)\ (3840)\ (39.5) - 19\ 132$

$23\ 260.044\ (\sin \alpha/2) + L = 2175.159$

Assume values for *L* and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2175.159	0	0	0
1000	0.050 52	2°53′	5°46′
0	.093 51	5°22′	10°44′

q. Compute conductor and overhead ground wire guying for a type 3AC structure (fig. 61). Assume conductor on inside of angle is guyed to top of center pole, and two outside conductors are guyed from the outside pole. Two conductors will be guyed off together, and one conductor and two overhead ground wires will be guyed off together.

For two conductors, one guy:

(2 cond.) ($2\,T_{\text{max.}}$ sin $\alpha/2$) (moment arm) + (2 cond.) (wind force on cond.) (moment arm) (1/2 SAS) = (2 guys) (allowable horizontal load on guy) (moment arm) – (wind on poles)

Metric

$$(2)\ (2)\ (33\ 362)\ (\sin \alpha/2)\ (13.868) + (2)\ (17.961)\ (13.868)\ (L/2)$$
$$= (17\ 080)\ (13.564) - (2)\ (12\ 969.75)$$

$1\ 850\ 656.86\ (\sin \alpha/2) + 498.166\ L/2 = 205\ 733.62$

$1\ 850\ 656.86\ (\sin \alpha/2) + 249.083\ L = 205\ 733.62$

$7429.88\ (\sin \alpha/2) + L = 825.964$

Assume values for *L* and solve for α:

L, m	sin α/2	α/2	α
600	0.030 41	1°44′	3°28′
300	.070 79	4°03′	8°06′
0	.111 17	6°23′	12°46′

U.S. Customary

$(2)\,(2)\,(7500)\,(\sin\alpha/2)\,(45.5) + (2)\,(1.231)\,(45.5)\,(L/2) = (3840)\,(44.5) - (2)\,(9566)$

$1\,365\,000\,(\sin\alpha/2) + 112.021\ L/2 = 170\,880 - 19\,132$

$1\,365\,000\,(\sin\alpha/2) + 56.01\ L = 151\,748$

$24\,370.648\,(\sin\alpha/2) + L = 2709.302$

Assume values for *L* and solve for α:

L, ft	sin α/2	α/2	α
2000	0.029 10	1°40′	3°20′
1000	.070 14	4°01′	8°02′
0	.111 17	6°23′	12°46′

For two conductors, two guys:

Metric

$1\,850\,656.86\,(\sin\alpha/2) + 249.083\ L = (2)\,(17\,080)\,(13.564) - (2)\,(12\,969.75)$

$7429.88\,(\sin\alpha/2) + L = 1756.068$

Assume values for *L* and solve for α:

L, m	sin α/2	α/2	α
600	0.155 60	8°57′	17°54′
300	.195 97	11°18′	22°36′
0	.236 35	13°40′	27°20′

U.S. Customary

$1\,365\,000\,(\sin\alpha/2) + 56.01\ L = (2)\,(3840)\,(44.5) - (2)\,(9566)$

$24\,370.648\,(\sin\alpha/2) + L = 5760.186$

Assume values for *L* and solve for α:

L, ft	sin α/2	α/2	α
2000	0.154 29	8°52′	17°44′
1000	.195 32	11°15′	22°30′
0	.236 36	13°40′	27°20′

For one conductor and two overhead ground wires, one guy:
Metric

$$(1)\ (2)\ (33\ 362)\ (\sin \alpha/2)\ (14.326) + (1)\ (17.961)\ (14.326)\ (L/2) + (2)\ (2)\ (21\ 418)\ (\sin \alpha/2)\ (14.326) + (2)\ (13.2318)\ (14.326)\ (L/2) = (17\ 080)\ (14.326) - (12\ 969.75)$$

$$6860.892\ (\sin \alpha/2) + L = 728.186$$

Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.018 68	1°04′	2°08′
300	.062 41	3°34′	7°08′
0	.106 14	6°05′	12°10′

U.S. Customary

$$(1)\ (2)\ (7500)\ (\sin \alpha/2)\ (47) + (1)\ (1.231)\ (47)\ (L/2) + (2)\ (2)\ (4815)\ (\sin \alpha/2)\ (47) + (2)\ (0.906)\ (47)\ (L/2) = (3840)\ (47) - 9566$$

$$22\ 517.410\ (\sin \alpha/2) + L = 2390.071$$

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.017 32	0°59′	1°58′
1000	.061 73	3°32′	7°04′
0	.106 14	6°05′	12°10′

For one conductor and two overhead ground wires, two guys:
Metric

$$2\ 183\ 225.096\ (\sin \alpha/2) + 318.213\ L = (2)\ (17\ 080)\ (14.326) - (12\ 969.75)$$
$$6860.882\ (\sin \alpha/2) + L = 1497.131$$

Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.130 76	7°30′	15°00′
300	.174 49	10°03′	20°06′
0	.218 21	12°36′	25°12′

U.S. Customary

$$1\ 610\ 220\ (\sin \alpha/2) + 71.510\ L = (2)\ (3840)\ (47) - (9566)$$
$$22\ 517.410\ (\sin \alpha/2) + L = 4913.914$$

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Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.129 41	7°26′	14°52′
1000	.173 82	10°00′	20°00′
0	.218 22	12°36′	25°12′

As the guy attachment for one conductor and two overhead ground wires is separated by only 762 mm (2.5 ft) from the guy attachment for the other two conductors and because the two-conductor load is located between the two guy attachment points, it is satisfactory to consider a total load (three conductors and two overhead ground wires) guyed from an imaginary point halfway between the two attachment points. The required number of guys (as calculated) could then be split between the two guy attachment points with very little load transferred through the pole between these attachment points.

Example

For two guys (one at each attachment point):

(2 cond.) (2 $T_{\text{max.}}$ sin $\alpha/2$) (moment arm) + (2 cond.) (wind force on cond.) (moment arm) (1/2 SAS) + (1 cond.) (2 $T_{\text{max.}}$ sin $\alpha/2$) (moment arm) + (1 cond.) (wind force on cond.) (moment arm) (1/2 SAS) + (2 OGW) (2 $T_{\text{max.}}$ sin $\alpha/2$) (moment arm) + (2 OGW) (wind force on OGW) (moment arm) (1/2 SAS) = (2 guys) (allowable horizontal load per guy) (moment arm) – (wind on poles)

Metric

$$\begin{aligned}&(2)\,(2)\,(33\ 362)\,(\sin \alpha/2)\,(13.868) + (2)\,(17.961)\,(13.868)\,(L/2)\\&\quad + (1)\,(2)\,(33\ 362)\,(\sin \alpha/2)\,(14.326) + (1)\,(17.961)\,(14.326)\,(L/2)\\&\quad + (2)\,(2)\,(21\ 418)\,(\sin \alpha/2)\,(14.326) + (2)\,(13.2318)\,(14.326)\,(L/2)\\&\quad = (2)\,(17\ 080)\,(13.945) - (3)\,(12\ 969.75)\end{aligned}$$

$4\ 033\ 881.960\,(\sin \alpha/2) + 567.296\,L = 437\ 451.95$

$7110.718\,(\sin \alpha/2) + L = 771.118$

Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.024 06	1°22′	2°44′
300	.060 63	3°28′	6°56′
0	.108 44	6°13′	12°26′

U.S. Customary

$$\begin{aligned}&(2)\,(2)\,(7500)\,(\sin \alpha/2)\,(45.5) + (2)\,(1.231)\,(45.5)\,(L/2)\\ &\quad + (1)\,(2)\,(7500)\,(\sin \alpha/2)\,(47) + (1)\,(1.231)\,(47)\,(L/2)\\ &\quad + (2)\,(2)\,(4815)\,(\sin \alpha/2)\,(47) + (2)\,(0.906)\,(47)\,(L/2)\\ &\quad = (2)\,(3840)\,(45.75) - (3)\,(9566)\end{aligned}$$

$2\,975\,220\,(\sin \alpha/2) + 127.521\,L = 322\,662$

$23\,331.216\,(\sin \alpha/2) + L = 2530.266$

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.022 73	1°18′	2°36′
1000	.065 59	3°45′	7°30′
0	.108 45	6°13′	12°26′

For three guys (two at upper guy attachment and one at lower):
Metric

$4\,033\,881.960\,(\sin \alpha/2) + 567.296\,L = (3)\,(17\,080)\,(13.945) - 38\,909.25$

$7110.718\,(\sin \alpha/2) + L = 1190.970$

Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.083 11	4°46′	9°32′
300	.125 30	7°12′	14°24′
0	.167 49	9°38′	19°16′

U.S. Customary

$2\,975\,220\,(\sin \alpha/2) + 127.521\,L = (3)\,(3840)\,(45.75) - 28\,698$

$23\,331.216\,(\sin \alpha/2) + L = 3907.921$

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.081 78	4°41′	9°22′
1000	.124 64	7°09′	14°18′
0	.167 50	9°38′	19°16′

For four guys (two at each attachment point):
Metric

$4\,033\,881.960\,(\sin \alpha/2) + 567.296\,L = (4)\,(17\,080)\,(13.945) - 38\,909.25$

$7110.718\,(\sin \alpha/2) + L = 1610.822$

Assume values for *L* and solve for α:

L, m	sin α/2	α/2	α
600	0.142 15	8°10′	16°20′
300	.184 34	10°37′	21°14′
0	.226 53	13°05′	26°10′

U.S. Customary

2 975 200 (sin $\alpha/2$) + 127.521 L = (4) (3840) (45.75) – 28 698
23 331.216 (sin $\alpha/2$) + L = 5285.576
Assume values for *L* and solve for α:

L, ft	sin α/2	α/2	α
2000	0.140 82	8°05′	16°10′
1000	.183 68	10°35′	21°10′
0	.226 54	13°05′	26°10′

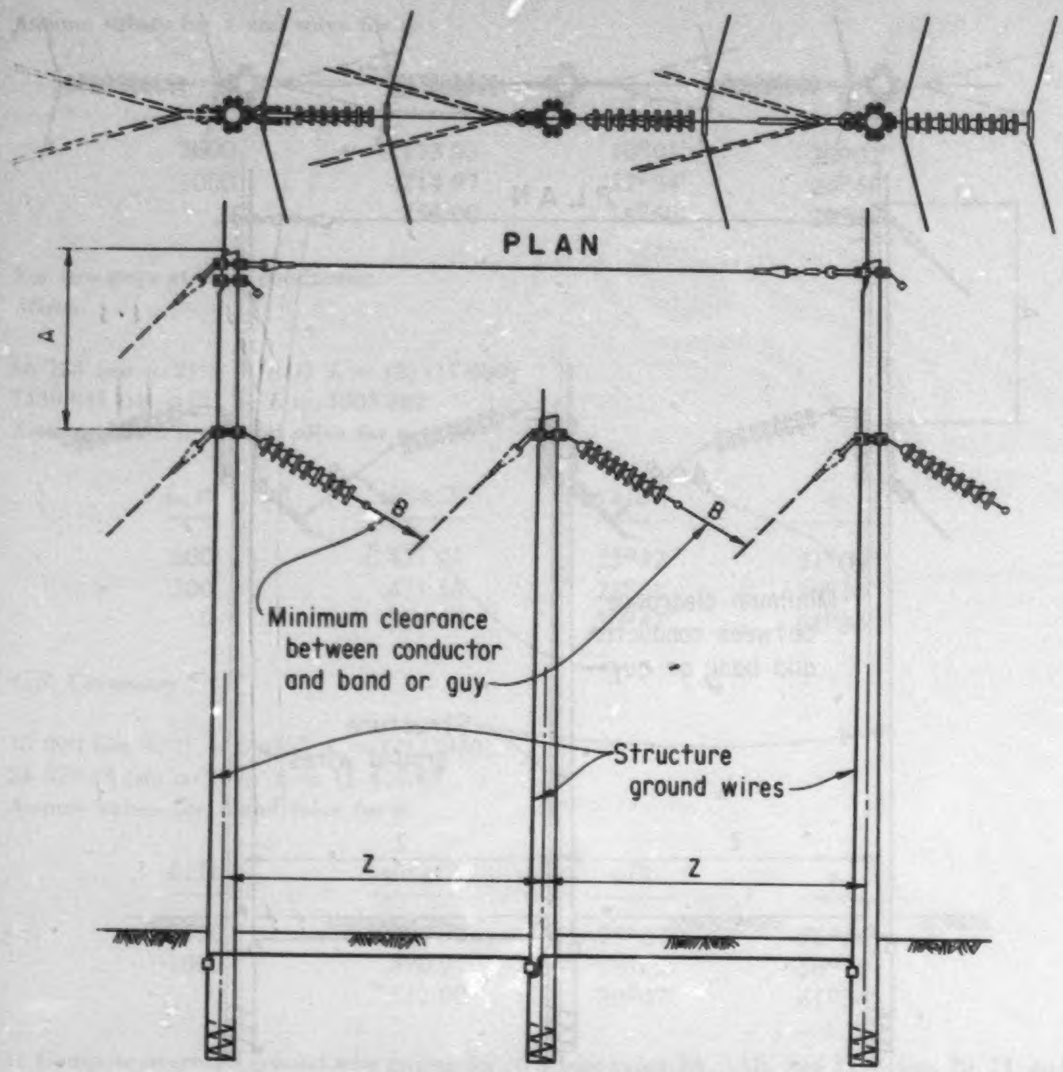
r. Compute conductor guying for structure types 3A (fig. 70) and 3AB (fig. 71).
For one guy at each conductor:
Metric

2 T(sin $\alpha/2$) + (wind force) ($L/2$) = 17 080
(2) (33 362) (sin $\alpha/2$) + [(47/1000) (0.383 04) (1000)]($L/2$) = 17 080
66 724 (sin $\alpha/2$) + 17.9607 $L/2$ = 17 080
66 724 (sin $\alpha/2$) + 8.9803 L = 17 080
7430.041 (sin $\alpha/2$) + L = 1901.941
Assume values for *L* and solve for α:

L, m	sin α/2	α/2	α
600	0.175 23	10°05′	20°10′
300	.215 60	12°27′	24°54′
0	.256 00	14°50′	29°40′

U.S. Customary

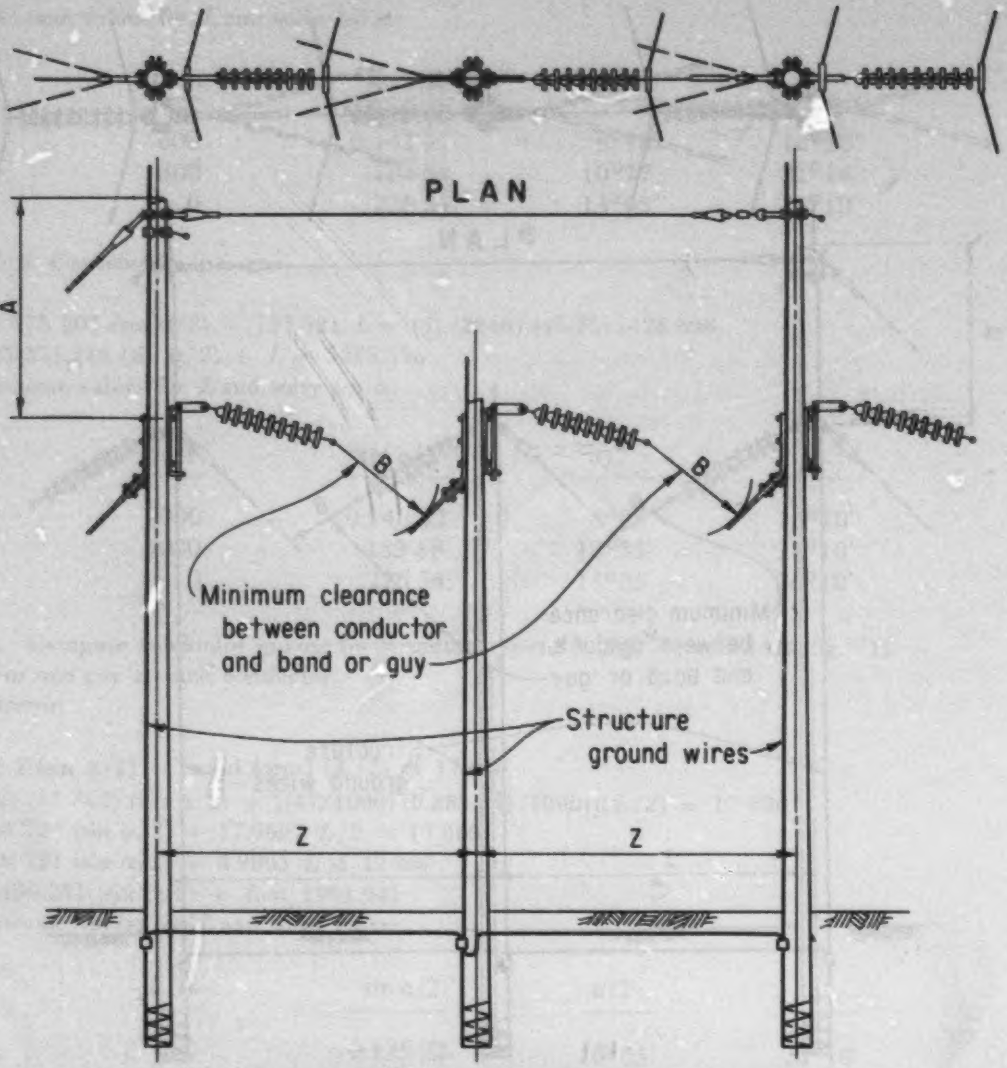
(2) (7500) (sin $\alpha/2$) + [(1.846/12) (8)] ($L/2$) = 3840
15 000 (sin $\alpha/2$) + 1.231 $L/2$ = 3840
15 000 (sin $\alpha/2$) + 0.6155 L = 3840
24 370.43 (sin $\alpha/2$) + L = 6238.83


PLAN
A
B
B
Minimum clearance between conductor and band or guy
Structure ground wires
Z
Z

TYPE 3A STRUCTURE

Voltage, kV	Metric, mm			U.S. Customary, ft-in		
	A	Z	B	A	Z	B
69	3048	3963	965	10-0	13-0	3-2
115	3048	5487	1397	10-0	18-0	4-7
138	3048	7011	1524	10-0	23-0	5-0
161	3048	7315	1676	10-0	24-0	5-6
230	3048	7620	1956	10-0	25-0	6-5

Figure 70.–Type 3A wood-pole structure. 104-D-1083.


PLAN
A
B
B
Minimum clearance between conductor and band or guy
Structure ground wires
Z
Z

TYPE 3AB STRUCTURE

Voltage, kV	Metric, mm			U.S. Customary, ft-in		
	A	Z	B	A	Z	B
69	3048	4420	965	10-0	14-6	3-2
115	3048	5182	1397	10-0	17-0	4-7
138	3048	7315	1524	10-0	24-0	5-0
161	3048	7620	1676	10-0	25-0	5-6

Figure 71.–Type 3AB wood-pole structure. 104-D-1084.

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.173 93	10°01′	20°02′
1000	.214 97	12°24′	24°48′
0	.256 00	14°50′	29°40′

For two guys at each conductor:
Metric

66 724 $(\sin \alpha/2)$ + 8.9803 L = (2) (17 080)
7430.041 $(\sin \alpha/2)$ + L = 3803.882
Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.431 21	25°32′	51°04′
300	.471 58	28°08′	56°16′
0	.511 96	30°47′	61°34′

U.S. Customary

15 000 $(\sin \alpha/2)$ + 0.6155 L = (2) (3840)
24 370.43 $(\sin \alpha/2)$ + L = 12 477.66
Assume values for L and solve for α:

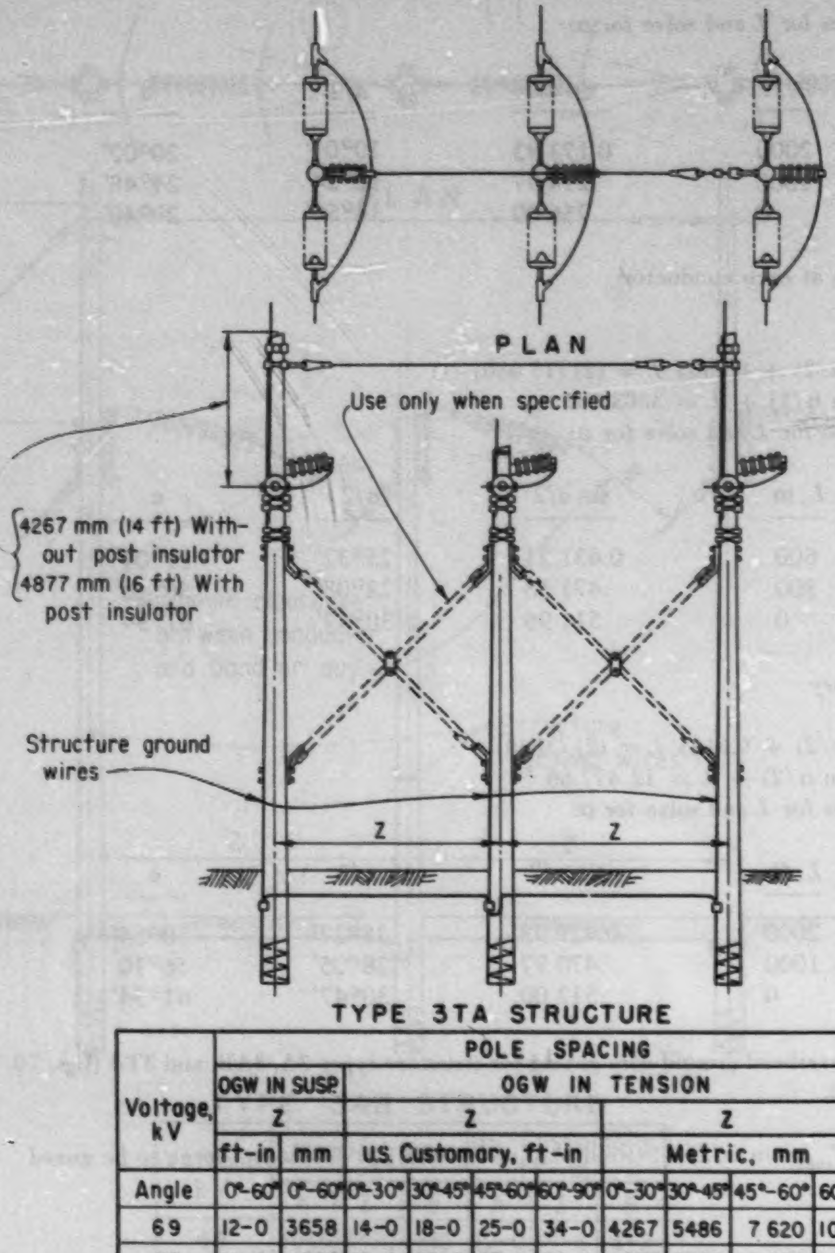
L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.429 93	25°27′	50°54′
1000	.470 97	28°05′	56°10′
0	.512 00	30°47′	61°34′

s. Compute overhead ground wire guying for structure types 3A, 3AB, and 3TA (figs. 70, 71, and 72, respectively).

(2 OGW) $(2 T_{\text{max.}} \sin \alpha/2)$ + (wind load on 2 OGW) = horizontal force to be guyed

For one guy:
Metric

(2) (2) (21 418) $(\sin \alpha/2)$ + [(34.544/1000) (0.383 04) (1000)] (2) $(L/2)$ = 17 080
85 672 $(\sin \alpha/2)$ + 26.4634 $L/2$ = 17 080
85 672 $(\sin \alpha/2)$ + 13.2317 L = 17 080
6474.754 $(\sin \alpha/2)$ + L = 1290.839


PLAN
Use only when specified
4267 mm (14 ft) Without post insulator
4877 mm (16 ft) With post insulator
Structure ground wires
Z
Z
TYPE 3TA STRUCTURE

Voltage, kV	POLE SPACING									
	OGW IN SUSP.		OGW IN TENSION							
	Z		Z				Z			
	ft-in	mm	U.S. Customary, ft-in				Metric, mm			
Angle	0°-60°	0°-60°	0°-30°	30°-45°	45°-60°	60°-90°	0°-30°	30°-45°	45°-60°	60°-90°
69	12-0	3658	14-0	18-0	25-0	34-0	4267	5486	7 620	10 363
115	14-0	4267	16-0	20-0	27-0	37-0	4877	6096	8 230	11 278
138	16-0	4877	18-0	22-0	29-0	39-0	5486	6706	8 839	11 887
161	20-0	6096	20-0	24-0	31-0	41-0	6096	7315	9 449	12 479
230	25-0	7620	23-0	26-0	33-0	43-0	7010	7924	10 058	13 106

Figure 72.–Type 3TA wood-pole structure. 104-D-1085.

Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.106 70	6°07′	12°14′
300	.153 03	8°48′	17°36′
0	.199 36	11°30′	23°00′

U.S. Customary

$(2)\ (2)\ (4815)\ (\sin \alpha/2) + [(1.36/12)\ (8)]\ (2)\ (L/2) = 3840$

$19\ 260\ (\sin \alpha/2) + 0.9066\ L = 3840$

$21\ 244.209\ (\sin \alpha/2) + L = 4235.605$

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.105 23	6°02′	12°04′
1000	.152 30	8°45′	17°30′
0	.199 37	11°30′	23°00′

For two guys:

Metric

$85\ 672\ (\sin \alpha/2) + 13.2317\ L = (2)(17\ 080)$

$6474.754\ (\sin \alpha/2) + L = 2581.679$

Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.306 06	17°49′	35°38′
300	.352 40	20°38′	41°16′
0	.398 73	23°30′	47°00′

U.S. Customary

$19\ 260\ (\sin \alpha/2) + 0.9066\ L = (2)(3840)$

$21\ 244.209\ (\sin \alpha/2) + L = 8471.211$

Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.304 61	17°44′	35°28′
1000	.351 68	20°35′	41°10′
0	.398 75	23°30′	47°00′

For three guys:
Metric

$85\,672\ (\sin \alpha/2) + 13.2317\ L = (3)(17\,080)$
$6474.754\ (\sin \alpha/2) + L = 3872.518$
Assume values for L and solve for α:

L, m	$\sin \alpha/2$	$\alpha/2$	α
600	0.505 43	30°21′	60°42′
300	.551 76	33°29′	66°58′
0	.598 10	36°44′	73°28′

U.S. Customary

$19\,260\ (\sin \alpha/2) + 0.9066\ L = (3)\ (3840)$
$21\,244.209\ (\sin \alpha/2) + L = 12\,706.817$
Assume values for L and solve for α:

L, ft	$\sin \alpha/2$	$\alpha/2$	α
2000	0.503 99	30°15′	60°30′
1000	.551 06	33°26′	66°52′
0	.598 13	36°44′	73°28′

t. Prepare guying data for structure type 3TA (fig. 72):
Assume structure has 18.3-m (60-ft) western red cedar poles without X-braces. Compute side guy requirements with no angle guys:

(OGW) (wind force on iced OGW) (moment arm) (1/2 SAS) + (cond.) (wind force on iced cond.) (moment arm) (1/2 SAS) = [(max. allowable moment on wood pole)/(safety factor of 2)] – (wind force on pole)

Metric

$(13.232)\ (15.697)\ (L/2) + (17.959)\ (10.973)\ (L/2) = (250\,555/2) - 12\,970$
$207.703\ L/2 + 197.064\ L/2 = 125\,277 - 12\,970$
$202.383\ L = 112\,307$
$L = 554.923$ m (maximum SAS without side guys)

U.S. Customary

$(0.9066)\ (51.5)\ (L/2) + (1.231)\ (36)\ (L/2) = (184\,800/2) - 9566$
$46.690\ L/2 + 44.316\ L/2 = 92\,400 - 9566$
$45.503\ L = 82\,834$
$L = 1820.41$ ft (maximum SAS without side guys)

With X-braces:
At 5.9436 m (19.5 ft) from top of structure:
Circumference of pole = 874 mm (34.4 in)
Diameter of pole = 278 mm (10.95 in)
Maximum allowable moment on pole = 81 603 N·m (60 187 lb·ft)
Moment on pole due to wind force:

(OGW) (wind force on iced OGW) (moment arm) (1/2 SAS) + (cond.) (wind force on iced cond.) (moment arm) (1/2 SAS) = [(max. allowable moment on wood pole)/(safety factor of 2)] – (wind force on pole)

Metric

$$\frac{FH^2\,(d_1 + 2d_2)}{6000} = \frac{[0.38304(1000)\,(5.9436)^2\,]\;[278.13 + (2)\,(202.18)]}{6000} = 1539.176\ \text{N·m}$$

$$(13.232)\,(5.7912)\,(L/2) + (17.959)\,(1.0668)\,(L/2) = (81\,603/2) - 1539$$
$$76.6291\ L/2 + 19.1587\ L/2 = 40\,801 - 1539$$
$$47.894\ L = 39\,262$$
$$L = 819.7686\ \text{m}$$ (maximum SAS without side guys)

U.S. Customary

$$\frac{FH^2\,(d_1 + 2d_2)}{72} = \frac{[8(19.5)^2\,]\;[10.95 + (2)\,(7.96)]}{72} = 1135.2575\ \text{lb·ft}$$

$$(0.9066)\,(19)\,(L/2) + (1.231)\,(3.5)\,(L/2) = (60\,187/2) - 1135$$
$$17.2254\ L/2 + 4.3085\ L/2 = 30\,093 - 1135$$
$$10.767\ L = 28\,958$$
$$L = 2689.51\ \text{ft}$$ (maximum SAS without side guys)

The National Electrical Safety Code does not require angle guys if line guys are used at tension structures; however, we use one single guy for each conductor on tension structures for line angles up to 60°. These angle guys will keep the structure from leaning into the angle. Guying requirements for the 3TA overhead ground wires were computed in paragraph 5.s.

u. Determine single span limits on structures due to galloping conductors:

The following paragraphs describe how to determine the spacing required between conductors and between conductors and overhead ground wires to prevent contact for a particular loading condition and span length with given conductors and overhead ground wires; or to determine the maximum permissible span for a given structure with given conductors and overhead ground wires.

For loading conditions of 13-mm (1/2-in) ice, 0.10-kPa (2-lb/ft^2) wind pressure, and at minus 1 °C (30 °F), determine the conductor and overhead ground wire sags for the given span length:

Conductor:

242 mm^2 (477 kcmil), ACSR, 24/7, NESC heavy loading

Ruling span	= 213.36 m (700 ft)

Maximum tension under full-load conditions of 13-mm (1/2-in) ice, 0.19-kPa (4-lb/ft²) wind, at –18 °C (0 °F) = 33 362N (7500 lb)

Sag under a load of 13-mm (1/2-in) ice, 0.10-kPa (2-lb/ft²) wind, at –1 °C (30 °F) = 5253 mm (17.23 ft)

OGW:

10-mm (3/8-in) high-strength steel, 7-wire, NESC heavy loading

Ruling span = 213.36 m (700 ft)

Maximum tension under full-load conditions = 21 418 N (4815 lb)

Sag under a load of 13-mm (1/2-in) ice, 0.10-kPa (2-lb/ft²) wind, at –1 °C (30 °F) = 4353 mm (14.28 ft)

Sag and tension calculation forms for this example were shown previously on figures 57, 58, 63, and 64.

Determine the angle of sideswing (θ) for the conductors and overhead ground wires:

The conductor has a force of 21.186 N/m (1.4517 lb/ft) with 13-mm (1/2-in) ice. A 0.10-kPa (2-lb/ft²) wind on the iced conductor equals 4.4898 N/m (0.3077 lb/ft). Therefore,

$$\theta = \tan^{-1}\frac{4.4898}{21.186} \text{ or } \left(\frac{0.3077}{1.4517}\right) = \tan^{-1} 0.211\,92 = 11^{\circ}58'.$$

The overhead ground wire has a force of 11.773 N/m (0.807 lb/ft) with 13-mm (1/2-in) ice. A 0.10-kPa (2-lb/ft²) wind on the iced overhead ground wire equals 3.3079 N/m (0.227 lb/ft). Therefore,

$$\theta = \tan^{-1}\frac{3.3079}{11.777} \text{ or } \left(\frac{0.227}{0.807}\right) = \tan^{-1} 0.280\,88 = 15^{\circ}42'.$$

Construct ellipses:

First, the locations of attachment points for the conductors and the overhead ground wires are drawn to scale to give an accurate configuration. Lines are then drawn from the attachment points at the respective angles of sideswing for the conductors and overhead ground wires. For tension structures, the conductors and overhead ground wires are located on these lines at their respective sag values below the attachment points. For suspension structures, the sag points must be extended the length of the suspension hardware for the overhead ground wires, and extended the length of the suspension insulator string for the conductors.

A line which will be the location of the major axis of an ellipse is then drawn through each sag point at an angle of 2θ from the line representing the conductor or overhead ground wire sideswing. The major axis of the ellipse is equal to the sag for full-sag ellipses, or one-half the sag for half-sag ellipses, plus 6 percent. The minor axis is equal to one-half of the major axis.

The ends and center of the major axis are marked with one end being placed a distance below the sag point equal to 3 percent of the applicable sag or half-sag value. The minor axis is marked perpendicular to the major axis at its center point. The ellipses may then be drawn by any acceptable method. There is no definite length of span where galloping will change from full-sag ellipses to half-sag ellipses. However, our experience has shown that, for our line locations and conditions, we should use full-sag ellipses in spans up to 183 m (600 ft) in length. In longer spans, the conductors

are likely to gallop in two or more loops so one-half size ellipses, with the major axis equal to 53 percent of the sag, should be used. If these ellipses do not overlap, the probability of contact between conductors or between conductors and overhead ground wires as a result of galloping is greatly reduced (see sec. 15). Full-sag ellipses for the maximum 183-m (600-ft) spans and the half-sag ellipses for the longer span limits should be made for each type of structure and case. Each of these limitations must be satisfied by the dimensions of the conductor and overhead ground wire configuration. Ellipses for the different structure types and cases to be considered for the structure limitation chart are shown on figures 73 through 87.

Paragraph 6.

To construct the structure limitation chart for wood structures:

a. Lay out the axes using the same scale factor for the horizontal scale and the lower part of the vertical scale (see pars. 5.b. and 5.d.). A different scale factor may be used for the sum of adjacent spans provided the deflection angle bias lines are adjusted accordingly.

b. Calibrate the horizontal axis to the right of the origin in degrees of line angle deflection with the degree calibration equal to the resultant tension at 15.5 °C (60 °F) with 0.19-kPa (4-lb/ft^2) wind pressure in one conductor due to the line deflection angle (par. 5.d.).

c. Calibrate the vertical axis above the origin in meters (feet) for the sum of adjacent spans. The calibrations should be at a distance above the origin equal to the wind pressure at 0.19 kPa (4 lb/ft^2) on a bare conductor of length equal to one-half the sum of the adjacent spans (par. 5.e.).

d. Calibrate the vertical axis below the origin in meters (feet) for the distance between low points of the bare (no ice) conductor equal to the vertical force of the conductor. The zero point should be displaced below the origin by a distance equal to one-half the vertical force of the insulator string (pars. 5.b. and 5.c.).

e. With a protractor, lay out the radial angles of insulator swing, and draw in heavy boundary lines for the insulator swing limits for each type of structure (see table 21, par. 1.c.).

f. Lay out the deflection angle bias lines at the computed angle (dependent upon scale factors used for the sum of adjacent spans scale and the distance between low points scale, see par. 5.f.). These bias lines are used to automatically add or subtract the wind pressure to or from the resultant tension due to a line deflection angle.

g. Layout lines showing the maximum permissible sum of adjacent spans for class 2 poles for all types of suspension structures (pars. 5.k., 5.l., and 5.m.), and maximum low point distance lines as calculated from the strength of the structures (pars. 5.g., 5.h., and 5.i.).

h. Draw lines to show the conductor low point limits permissible by the addition of various sizes of holddowns to the bottom of the insulator strings (par. 5.j.). A line for each size of insulator holddown is drawn parallel to the insulator string swing limit line for the type HS and HSB structures. These lines are offset vertically from the insulator string swing limit line by values obtained by multiplying the vertical force of each holddown by the low point scale factor (par. 5.j.).

i. Plot the single insulator string limit line at the resultant load on the insulator string equal to 35 585 N (8000 lb) for 88 965-N (20 000-lb) units under maximum loading conditions (par. 5.n.).

j. Add the bias lines for determining the limitation of single insulator strings to the sum of adjacent spans chart (par. 5.o.).

The structure limitation charts for wood structures are shown on figures 88 through 91.

Paragraph 7.

To construct the angle guying chart for suspension wood structures:

a. Use the same line deflection angle horizontal axis as used for the structure limitation chart.

b. Superimpose the guying chart on the deflection angle bias lines, or repeat the vertical axis calibration (sum of adjacent spans) using the same scale used for the structure limitation chart.

c. From the calculations for the number of angle guys required for the various types of structures under full-load conditions (pars. 5.p., q., r., and s.), plot lines separating the zones for different quantities of guys. Some of the limitations calculated may be unnecessary because some of the limit lines may be very close to each other if they are all plotted. Some of these limitations may be combined with others to keep the chart clean, but care must be taken to eliminate the right lines so that all guying requirements are satisfied. Standard guying drawings must be checked for the number of guys required by various guy arrangements, and the required quantities coordinated with the number of guys required to satisfy the calculated guy requirements. The coordinated quantities should be indicated on the structure guying chart. No guying is required for a line angle up to 1°, but at least one angle guy per suspension structure should be used for all line deflection angles greater than 1°. A vertical line at the 1° mark should be drawn and labeled to indicate the area on the chart where an angle guy is not required. Guying charts are shown on figures 92 and 93. A typical standard guying arrangement drawing for the type 3TA structure has been included as figure 94.

Type HS Structure
289.5-m (950-ft) Span
Based on 213.4-m (700-ft) ruling span
3658-mm (12-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Half-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	9674	(31.74)
Half sag	4837	(15.87)
+6%	290	(0.95)
Major axis	5127	(16.82)
Minor axis	2563	(8.41)

θ = 11° 58′

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	8016	(26.30)
Half sag	4008	(13.15)
+6%	240	(0.79)
Major axis	4248	(13.94)
Minor axis	2124	(6.97)

θ = 15° 42′

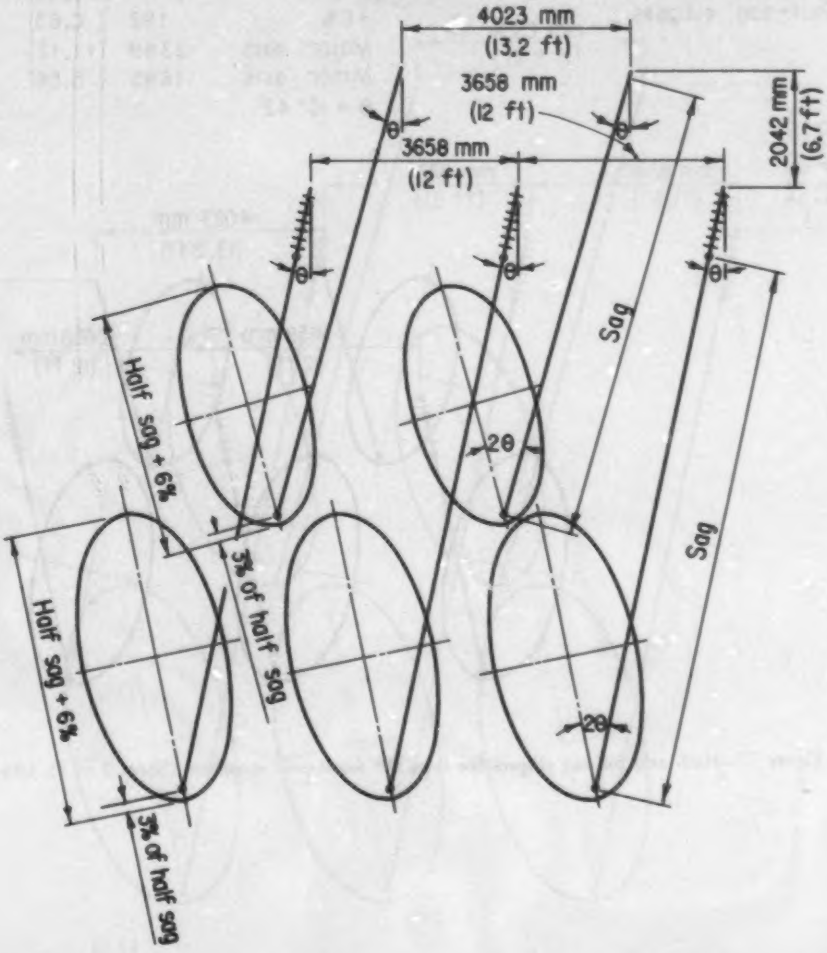

4023 mm
(13.2 ft)
3658 mm
(12 ft)
3658 mm
(12 ft)
2042 mm
(6.7 ft)
θ
θ
θ
θ
θ
Sag
Sag
Half sag + 6%
Half sag + 6%
3% of half sag
3% of half sag
2θ
2θ

Figure 73.–Half- and full-sag ellipses for type HS wood-pole structure (Sheet 1 of 2). 104-D-1086-1.

Type HS Structure
183-m (600-ft) Span
Based on 213.4-m (700-ft)
ruling span
3658-mm (12-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm^2 (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	3852	(12.64)
+6%	231	(0.76)
Major axis	4083	(13.40)
Minor axis	2042	(6.70)

$\theta = 11° 58'$

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	3197	(10.49)
+6%	192	(0.63)
Major axis	3389	(11.12)
Minor axis	1695	(5.56)

$\theta = 15° 42'$

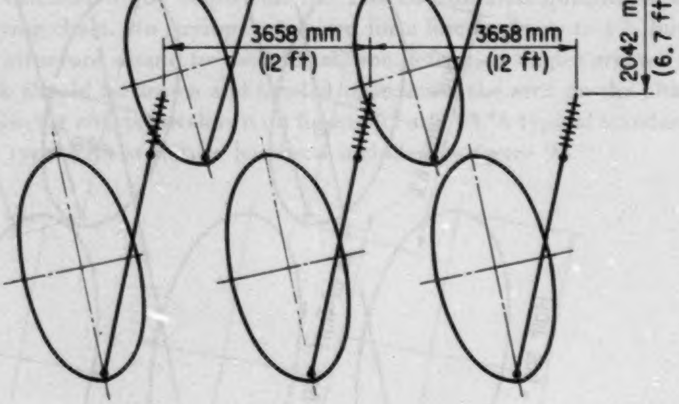


Figure 73.–Half- and full-sag ellipses for type HS wood-pole structure (Sheet 2 of 2). 104-D-1086-2.

Type HSB Structure
305.4-m (1000-ft) Span
Based on 213.4-m (700-ft) ruling span
3658-mm (12-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Half-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	10 717	(35.16)
Half-sag	5 359	(17.58)
+6%	321	(1.05)
Major axis	5 680	(18.63)
Minor axis	2 840	(9.32)

θ = 11° 58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	8882	(29.14)
Half-sag	4441	(14.57)
+6%	266	(0.87)
Major axis	4707	(15.44)
Minor axis	2353	(7.72)

θ = 15° 42'

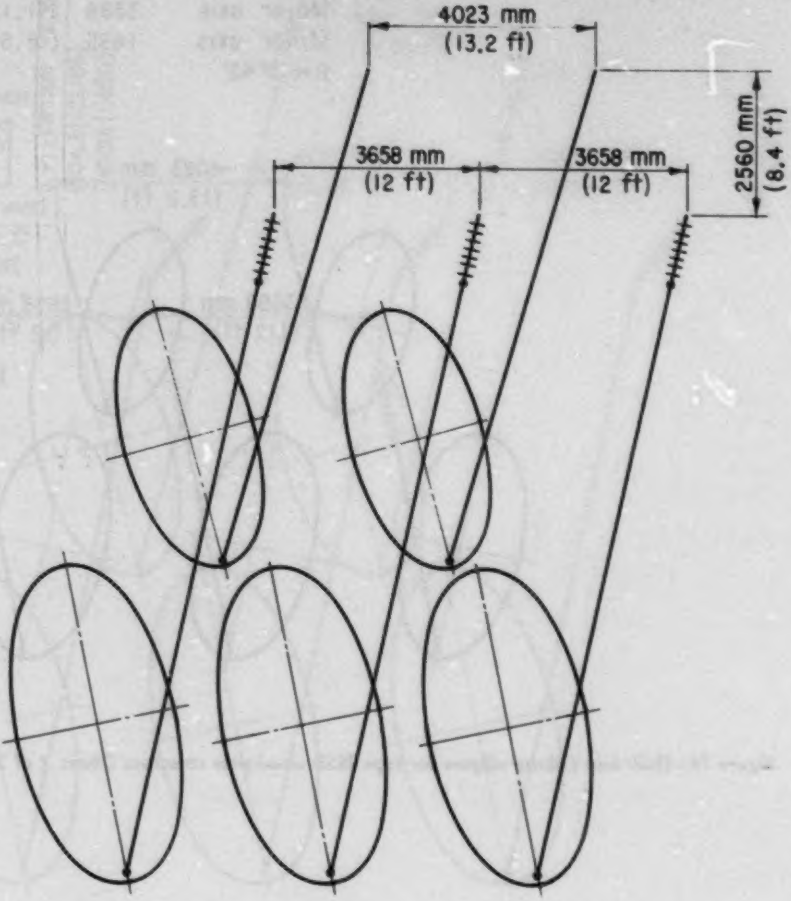


Figure 74.–Half- and full-sag ellipses for type HSB wood-pole structure (Sheet 1 of 2). 104-D-1087-1.

Type HSB Structure
183-m (600-ft) Span
Based on 213.4-m (700-ft) ruling span
3658-mm (12-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension = 33 362 N (7500 lb)
OGW full-load tension = 21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm^2 (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	3852	(12.64)
+6%	231	(0.76)
Major axis	4083	(13.40)
Minor axis	2042	(6.70)

$\theta = 11°58'$

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	3197	(10.49)
+6%	192	(0.63)
Major axis	3389	(11.12)
Minor axis	1695	(5.56)

$\theta = 15°42'$

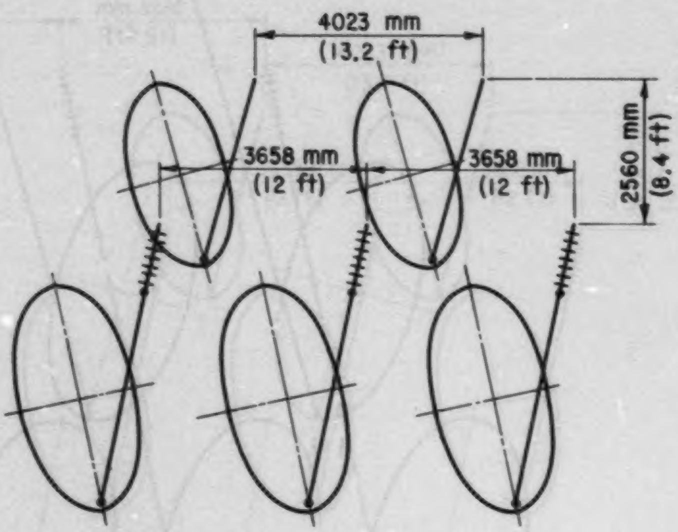


Figure 74.–Half- and full-sag ellipses for type HSB wood-pole structure (Sheet 2 of 2). 104-D-1087-2.

Type 3AC Structure
10° Line Angle
304.8-m (1000-ft) Span
Based on 213.4-m (700-ft) ruling span
4267-mm (14-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension = 33 362 N (7500 lb)
OGW full-load tension = 21 418 N (4815 lb)
Half-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	10 717	(35.16)
Half-sag	5 359	(17.58)
+6%	321	(1.05)
Major axis	5 680	(18.63)
Minor axis	2 840	(9.32)

$\theta = 11°58'$

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	8882	(29.14)
Half-sag	4441	(14.57)
+6%	266	(0.87)
Major axis	4707	(15.44)
Minor axis	2353	(7.72)

$\theta = 15° 42'$

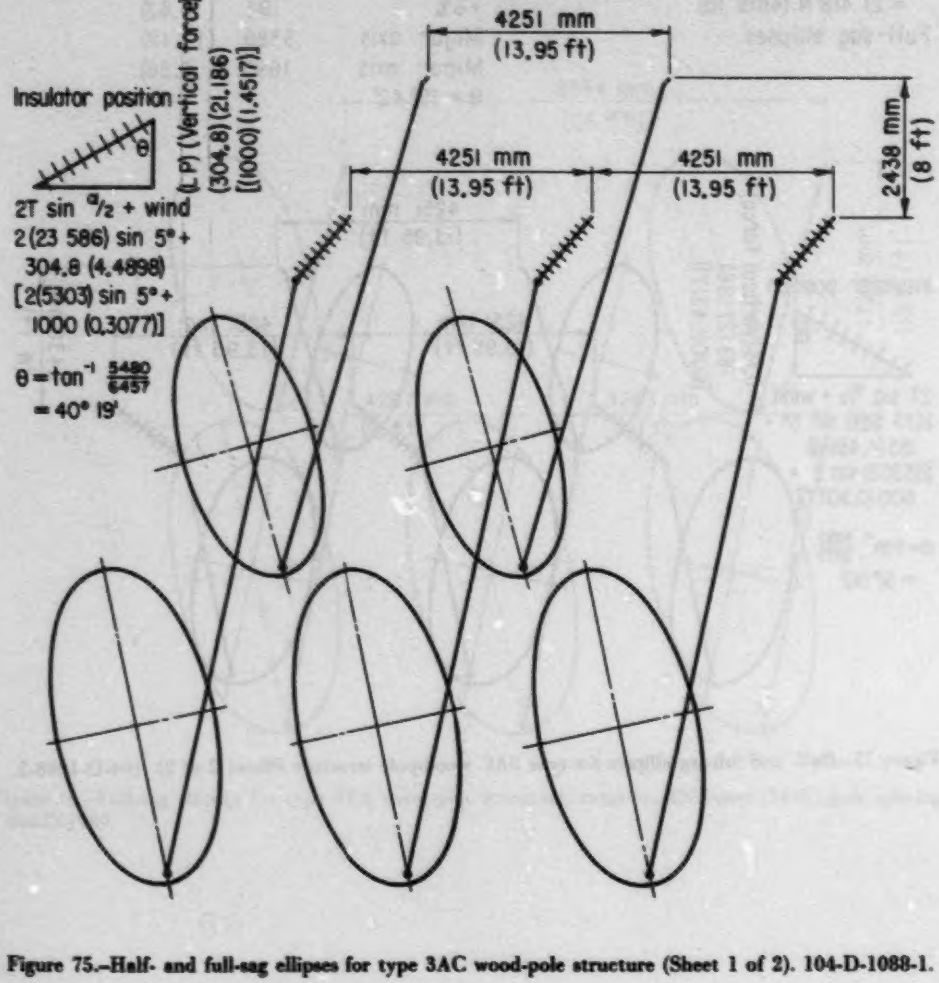

4251 mm
(13.95 ft)
4251 mm
(13.95 ft)
4251 mm
(13.95 ft)
2438 mm
(8 ft)
Insulator position
θ
(L P) (Vertical force)
(304.8) (21.186)
[(1000) (1.4517)]
2T sin a/2 + wind
2(23 586) sin 5° +
304.8 (4.4898)
[2(5303) sin 5° +
1000 (0.3077)]
θ = tan⁻¹ 5480/6457
= 40° 19'

Figure 75.–Half- and full-sag ellipses for type 3AC wood-pole structure (Sheet 1 of 2). 104-D-1088-1.

Type 3AC Structure
10° Line Angle
183-m (600-ft) Span
Based on 213.4-m (700-ft) ruling span
4267-mm (14-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension = 33 362 N (7500 lb)
OGW full-load tension = 21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	3852	(12.64)
+6%	231	(0.76)
Major axis	4083	(13.40)
Minor axis	2042	(6.70)

θ = 11°58′

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	3197	(10.49)
+6%	192	(0.63)
Major axis	3389	(11.12)
Minor axis	1695	(5.56)

θ = 15° 42′

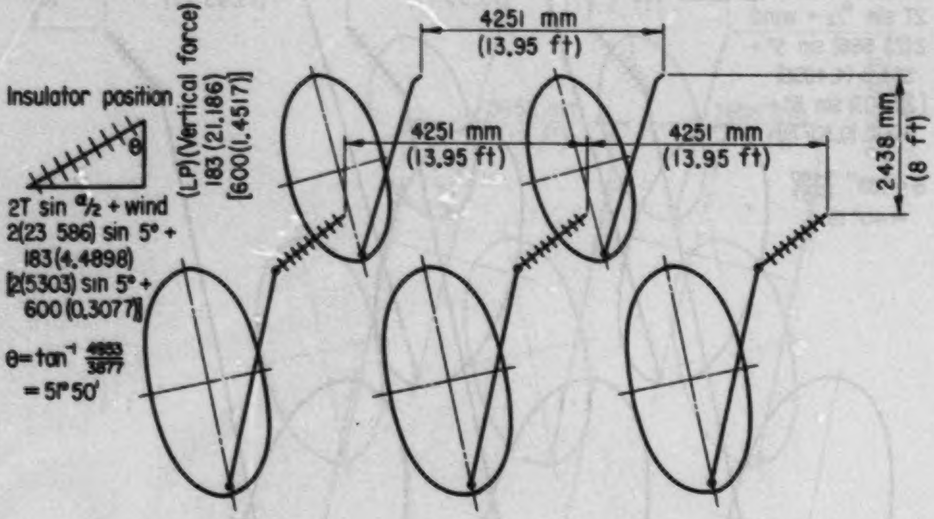

4251 mm
(13.95 ft)
4251 mm
(13.95 ft)
4251 mm
(13.95 ft)
2438 mm
(8 ft)
Insulator position
θ
(LP)(Vertical force)
183 (21.186)
[600(1.4517)]
2T sin α/2 + wind
2(23 586) sin 5° +
183(4.4898)
[2(5303) sin 5° +
600 (0.3077)]
θ= tan⁻¹ 4933/3877
= 51°50′

Figure 75.–Half- and full-sag ellipses for type 3AC wood-pole structure (Sheet 2 of 2). 104-D-1088-2.

Type 3TA Structure
Tangent, OGW in tension
213-m (700-ft) Span
4267-mm (14-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
=33 362 N (7500 lb)
OGW full-load tension
=21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	5253	(17.23)
+6 %	315	(1.03)
Major axis	5568	(18.26)
Minor axis	2784	(9.13)

θ = 11°58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	4353	(14.28)
+6 %	261	(0.86)
Major axis	4614	(15.14)
Minor axis	2307	(7.57)

θ = 15°42'

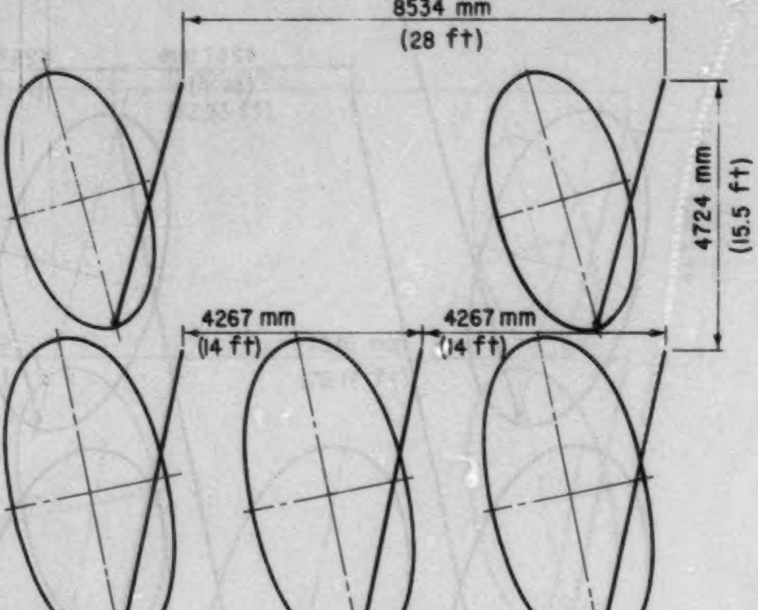


Figure 76.–Full-sag ellipses for type 3TA wood-pole structure, tangent, 4267-mm (14-ft) pole spacing. 104-D-1089.

Conductor: 242 mm^2 (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	12 966	(42.54)
Half sag	6483	(21.27)
+6 %	389	(1.27)
Major axis	6872	(22.54)
Minor axis	3436	(11.27)

θ = 11°58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	10 747	(35.26)
Half sag	5374	(17.63)
+6 %	322	(1.06)
Major axis	5696	(18.69)
Minor axis	2848	(9.35)

θ = 15°42'

Type 3TA Structure
Tangent, OGW in tension
335-m (1100-ft) Span
4267-mm (14-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
=33 362 N (7500 lb)
OGW full-load tension
=21 418 N (4815 lb)
Half-sag ellipses

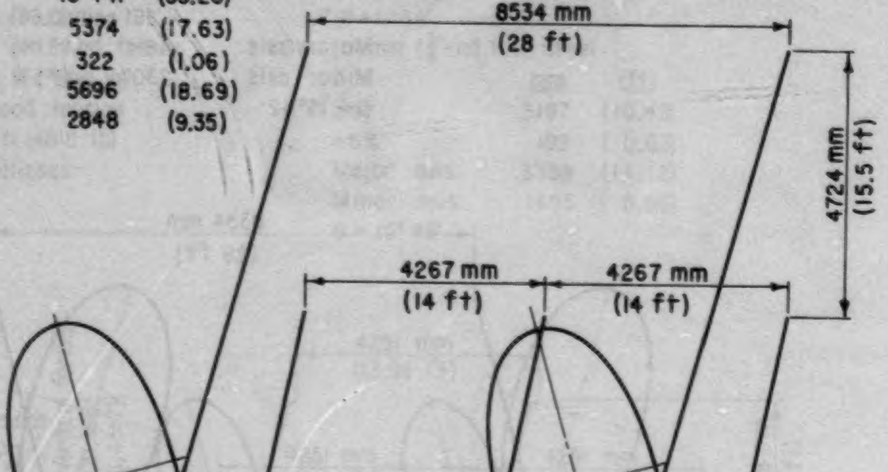


Figure 77.–Half-sag ellipses for type 3TA wood-pole structure, tangent, 4267-mm (14-ft) pole spacing. 104-D-1090.

Type 3TA Structure
90° Line angle, OGW in tension
Without post insulator for jumper
198-m (650-ft) Span
11 278-mm (37-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
=33 362 N (7500 lb)
OGW full-load tension
=21 418 N (4815 lb)
Full-sag ellipses
Only one OGW and two conductors
are shown

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	4526	(14.86)
+ 6 %	272	(0.89)
Major axis	4798	(15.75)
Minor axis	2399	(7.88)

θ = 11° 58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	3751	(12.31)
+ 6 %	225	(0.74)
Major axis	3976	(13.05)
Minor axis	1988	(6.53)

θ = 15° 42'

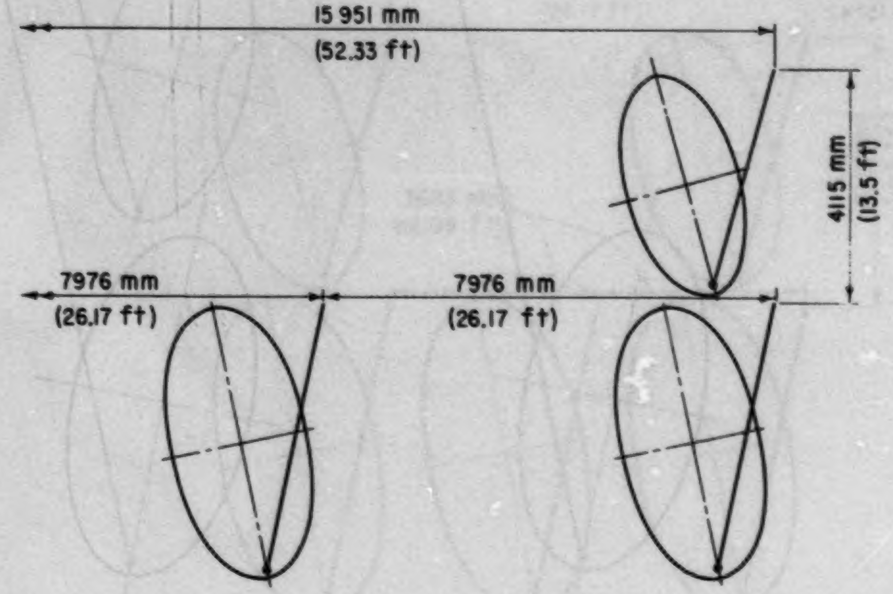
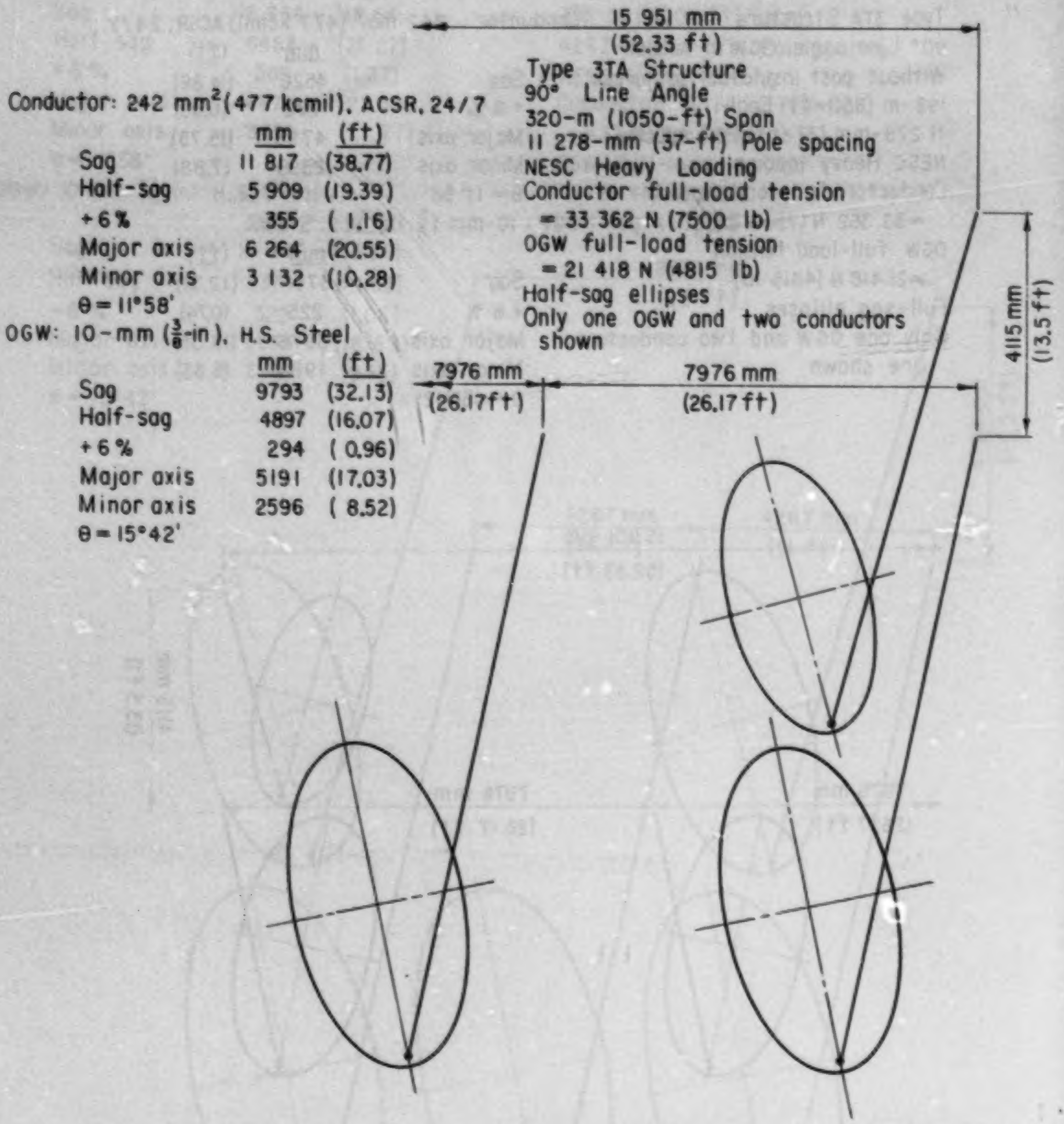


Figure 78.–Full-sag ellipses for type 3TA wood-pole structure, 90° line angle, 11 278-mm (37-ft) pole spacing. 104-D-1091.



Conductor: 242 mm^2 (477 kcmil), ACSR, 24/7

	mm	(ft)
Sag	11 817	(38.77)
Half-sag	5 909	(19.39)
+6 %	355	(1.16)
Major axis	6 264	(20.55)
Minor axis	3 132	(10.28)

θ = 11°58'

OGW: 10-mm ($\frac{3}{8}$-in), H.S. Steel

	mm	(ft)
Sag	9793	(32.13)
Half-sag	4897	(16.07)
+6 %	294	(0.96)
Major axis	5191	(17.03)
Minor axis	2596	(8.52)

θ = 15°42'

Type 3TA Structure
90° Line Angle
320-m (1050-ft) Span
11 278-mm (37-ft) Pole spacing
NESC Heavy Loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Half-sag ellipses
Only one OGW and two conductors shown

Figure 79.–Half-sag ellipses for type 3TA wood-pole structure, 90° line angle, 11 278-mm (37-ft) pole spacing. 104-D-1092.

Type 3TA Structure
60° Line angle, OGW in tension
213-m (700-ft) Span
4267-mm (14-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
=33 362 N (7500 lb)
OGW full-load tension
=21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm^2 (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	5253	(17.23)
+6 %	315	(1.03)
Major axis	5568	(18.26)
Minor axis	2784	(9.13)

θ = 11°58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	4353	(14.28)
+6 %	261	(0.86)
Major axis	4614	(15.14)
Minor axis	2307	(7.57)

θ = 15°42'

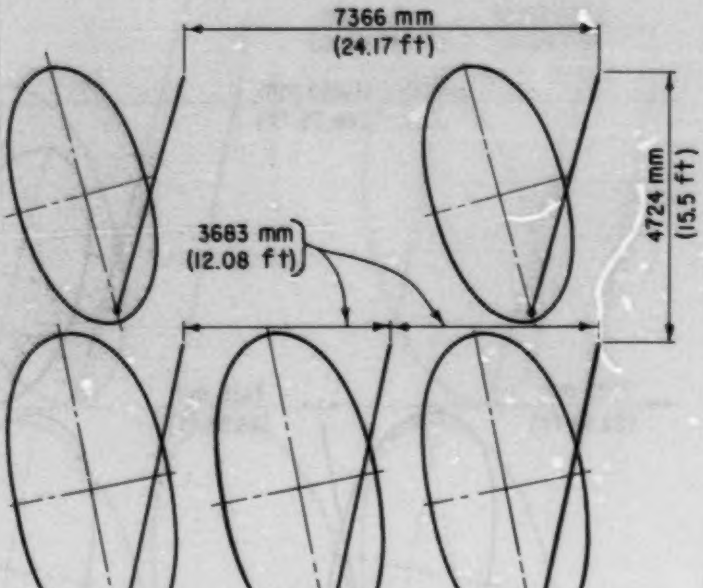


Figure 80.–Full-sag ellipses for type 3TA wood-pole structure, 60° line angle, 4267-mm (14-ft) pole spacing. 104-D-1093.

Type 3TA Structure
60° Line angle, OGW in tension
213-m (700-ft) Span
8230-mm (27-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
=33 362 N (7500 lb)
OGW full-load tension
=21 418 N (4815 lb)
Full-sag ellipses
Only one OGW and two conductors are shown

Conductor: 242 mm^2 (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	5253	(17.23)
+ 6 %	315	(1.03)
Major axis	5568	(18.26)
Minor axis	2784	(9.13)

θ = 11° 58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	4353	(14.28)
+ 6 %	261	(0.86)
Major axis	4614	(15.14)
Minor axis	2307	(7.57)

θ = 15°42'

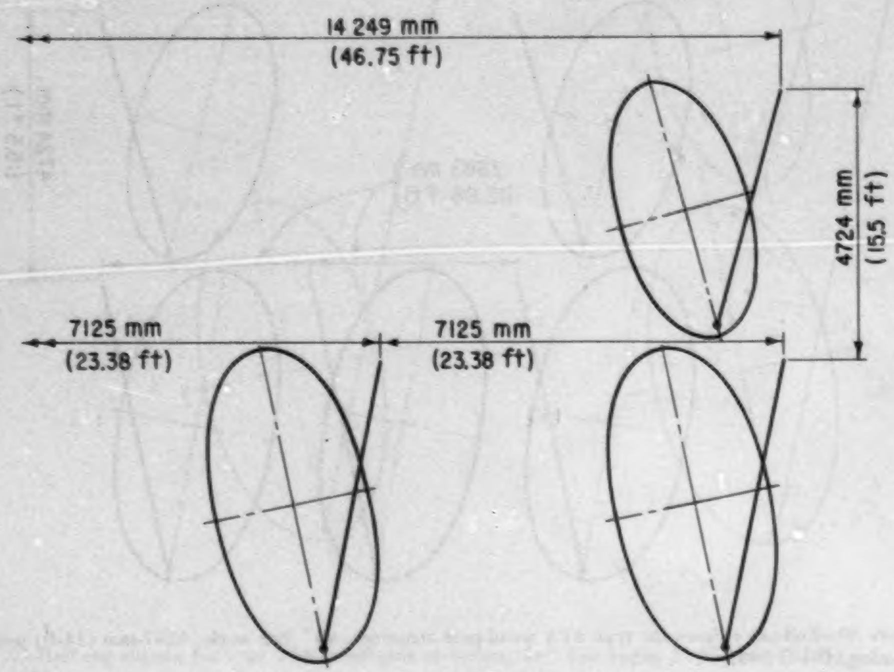
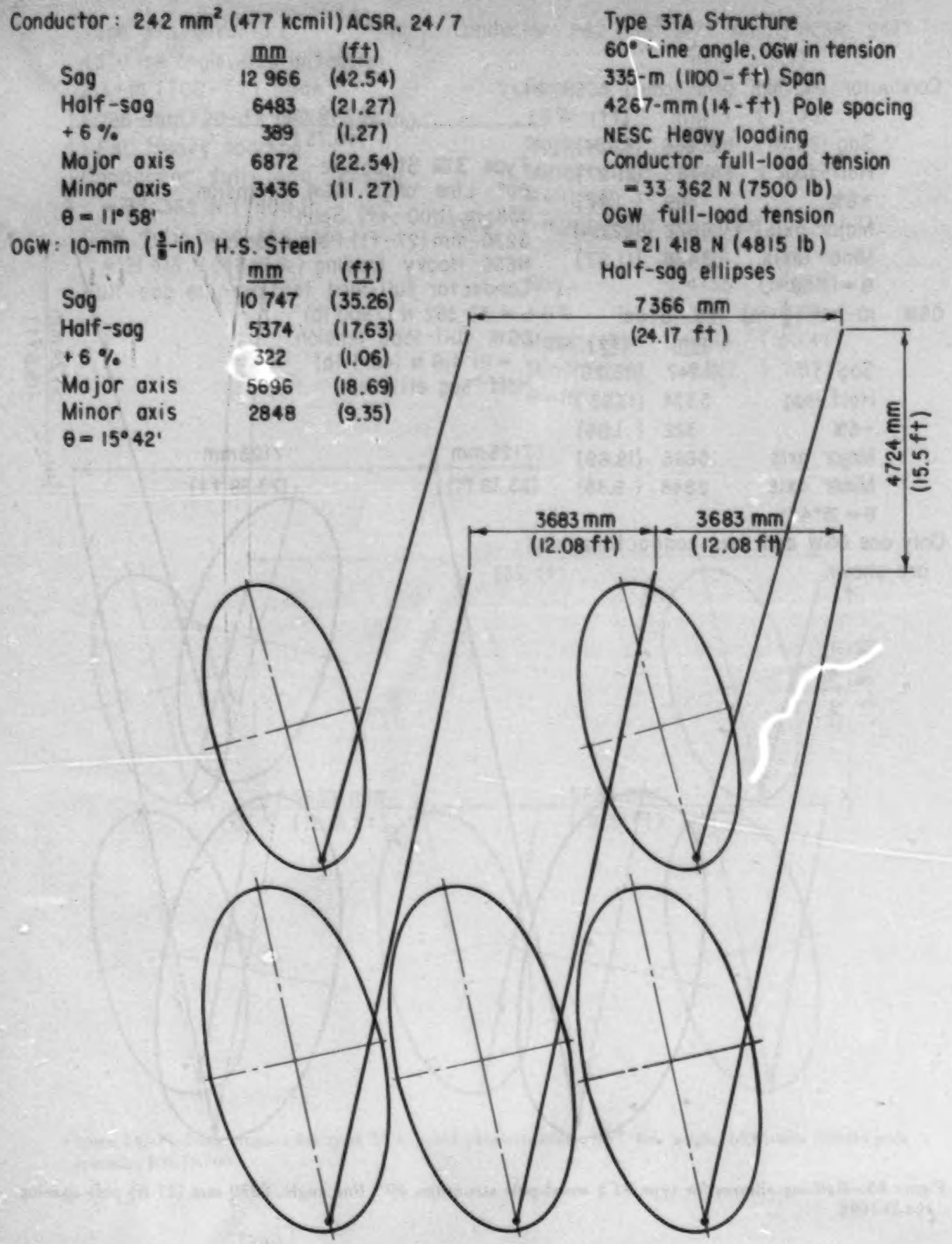


Figure 81.–Full-sag ellipses for type 3TA wood-pole structure, 60° line angle, 8230-mm (27-ft) pole spacing. 104-D-1094.



Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	12 966	(42.54)
Half-sag	6483	(21.27)
+ 6 %	389	(1.27)
Major axis	6872	(22.54)
Minor axis	3436	(11.27)

θ = 11° 58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	10 747	(35.26)
Half-sag	5374	(17.63)
+ 6 %	322	(1.06)
Major axis	5696	(18.69)
Minor axis	2848	(9.35)

θ = 15° 42'

Type 3TA Structure
60° Line angle, OGW in tension
335-m (1100-ft) Span
4267-mm (14-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Half-sag ellipses

Figure 82.–Half-sag ellipses for type 3TA wood-pole structure, 60° line angle, 4267-mm (14-ft) pole spacing. 104-D-1095.

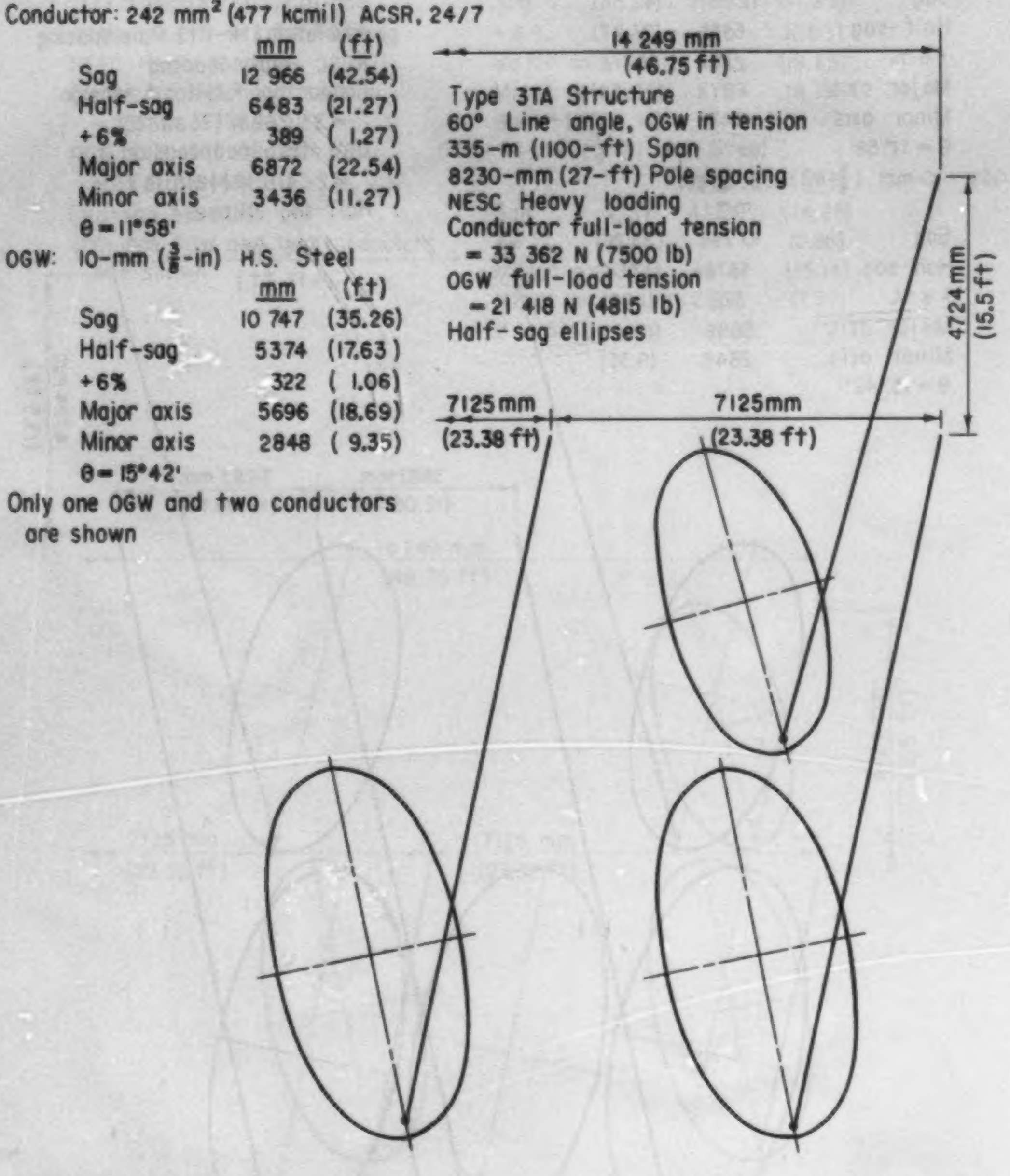

Conductor: 242 mm² (477 kcmil) ACSR, 24/7
mm (ft)
Sag 12 966 (42.54)
Half-sag 6483 (21.27)
+6% 389 (1.27)
Major axis 6872 (22.54)
Minor axis 3436 (11.27)
θ = 11°58'
OGW: 10-mm (3/8-in) H.S. Steel
mm (ft)
Sag 10 747 (35.26)
Half-sag 5374 (17.63)
+6% 322 (1.06)
Major axis 5696 (18.69)
Minor axis 2848 (9.35)
θ = 15°42'
Only one OGW and two conductors are shown
14 249 mm (46.75 ft)
Type 3TA Structure
60° Line angle, OGW in tension
335-m (1100-ft) Span
8230-mm (27-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension = 33 362 N (7500 lb)
OGW full-load tension = 21 418 N (4815 lb)
Half-sag ellipses
4724 mm (15.5 ft)
7125 mm (23.38 ft)
7125 mm (23.38 ft)

Figure 83.–Half-sag ellipses for type 3TA wood-pole structure, 60° line angle, 8230-mm (27-ft) pole spacing. 104-D-1096.

Type 3TA Structure
45° Line angle, OGW in tension
213-m (700-ft) Span
6096-mm (20-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	5253	(17.23)
+6%	315	(1.03)
Major axis	5568	(18.26)
Minor axis	2784	(9.13)

θ = 11°58'

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	4353	(14.28)
+6%	261	(0.86)
Major axis	4614	(15.14)
Minor axis	2307	(7.57)

θ = 15°42'

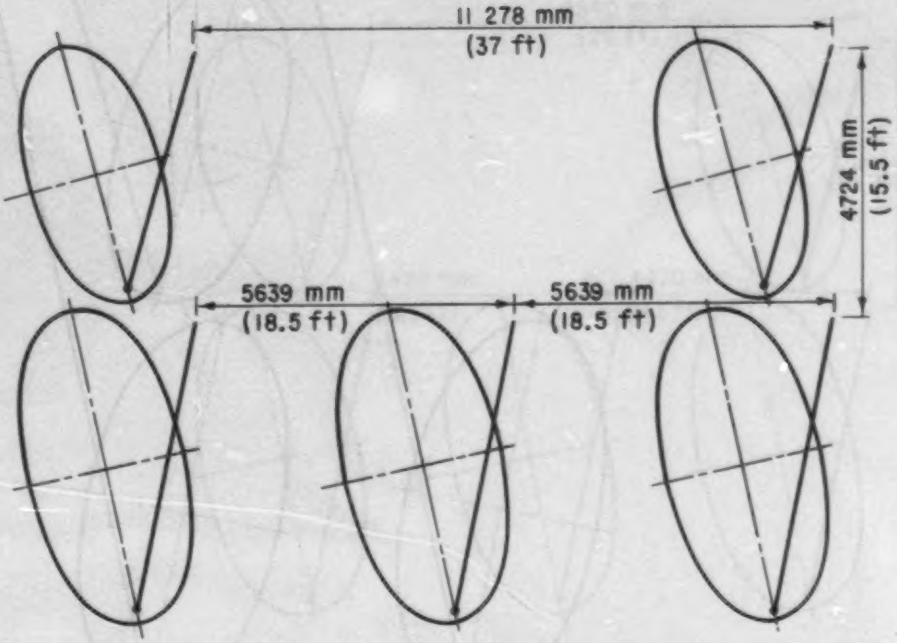
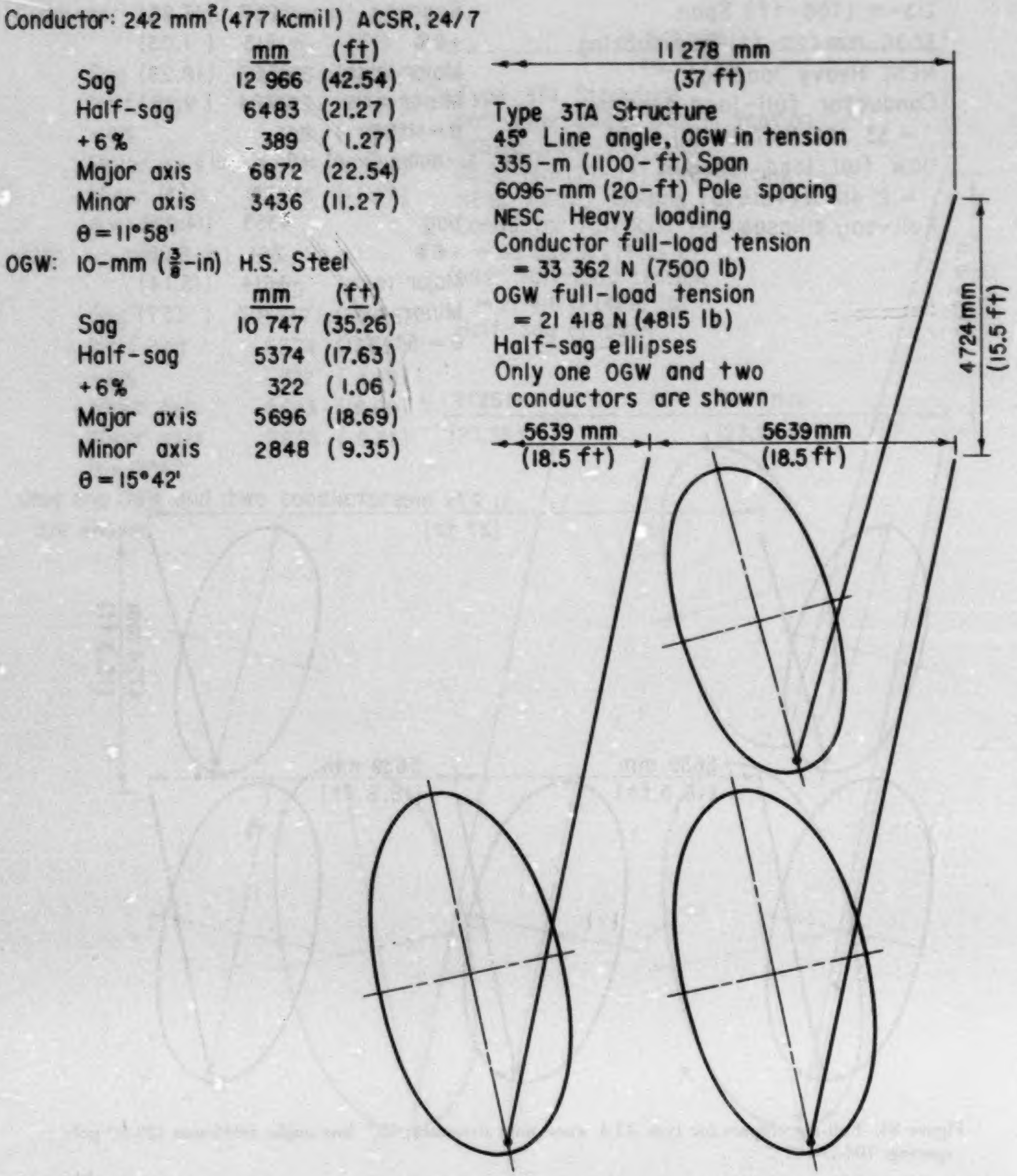


Figure 84.–Full-sag ellipses for type 3TA wood-pole structure, 45° line angle, 6096-mm (20-ft) pole spacing. 104-D-1097.



Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	12 966	(42.54)
Half-sag	6483	(21.27)
+6%	389	(1.27)
Major axis	6872	(22.54)
Minor axis	3436	(11.27)

θ = 11°58'

OGW: 10-mm (3/8-in) H.S. Steel

	mm	(ft)
Sag	10 747	(35.26)
Half-sag	5374	(17.63)
+6%	322	(1.06)
Major axis	5696	(18.69)
Minor axis	2848	(9.35)

θ = 15°42'

Type 3TA Structure
45° Line angle, OGW in tension
335-m (1100-ft) Span
6096-mm (20-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Half-sag ellipses
Only one OGW and two conductors are shown

Figure 85.–Half-sag ellipses for type 3TA wood-pole structure, 45° line angle, 6096-mm (20-ft) pole spacing. 104-D-1098.

Type 3TA Structure
30° Line angle, OGW in tension
213-m (700-ft) Span
4572-mm (15-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
=33 362 N (7500 lb)
OGW full-load tension
=21 418 N (4815 lb)
Full-sag ellipses

Conductor: 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	5253	(17.23)
+6 %	315	(1.03)
Major axis	5568	(18.26)
Minor axis	2784	(9.13)

$\theta = 11°58'$

OGW: 10-mm ($\frac{3}{8}$-in) H.S. Steel

	mm	(ft)
Sag	4353	(14.28)
+6 %	261	(0.86)
Major axis	4614	(15.14)
Minor axis	2307	(7.57)

$\theta = 15°42'$

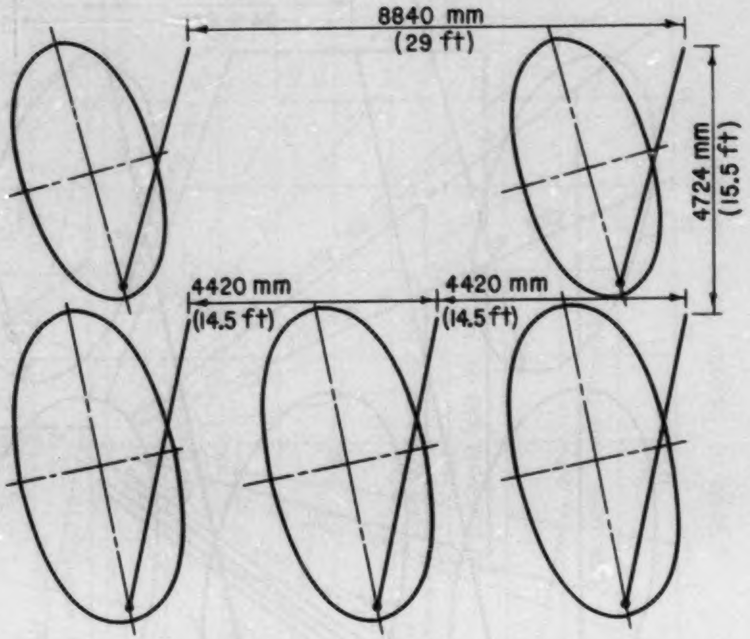


Figure 86.–Full-sag ellipses for type 3TA wood-pole structure, 30° line angle, 4572-mm (15-ft) pole spacing. 104-D-1099.

Conductor : 242 mm² (477 kcmil) ACSR, 24/7

	mm	(ft)
Sag	12 966	(42.54)
Half-sag	6483	(21.27)
+ 6 %	389	(1.27)
Major axis	6872	(22.54)
Minor axis	3436	(11.27)

θ = 11° 58'

OGW: 10-mm ($\frac{3}{8}$-in) H. S. Steel

	mm	(ft)
Sag	10 747	(35.26)
Half-sag	5374	(17.63)
+ 6 %	322	(1.06)
Major axis	5696	(18.69)
Minor axis	2848	(9.35)

θ = 15° 42'

Type 3TA Structure
30° Line angle, OGW in tension
335-m (1100-ft) Span
4572-mm (15-ft) Pole spacing
NESC Heavy loading
Conductor full-load tension
= 33 362 N (7500 lb)
OGW full-load tension
= 21 418 N (4815 lb)
Half-sag ellipses

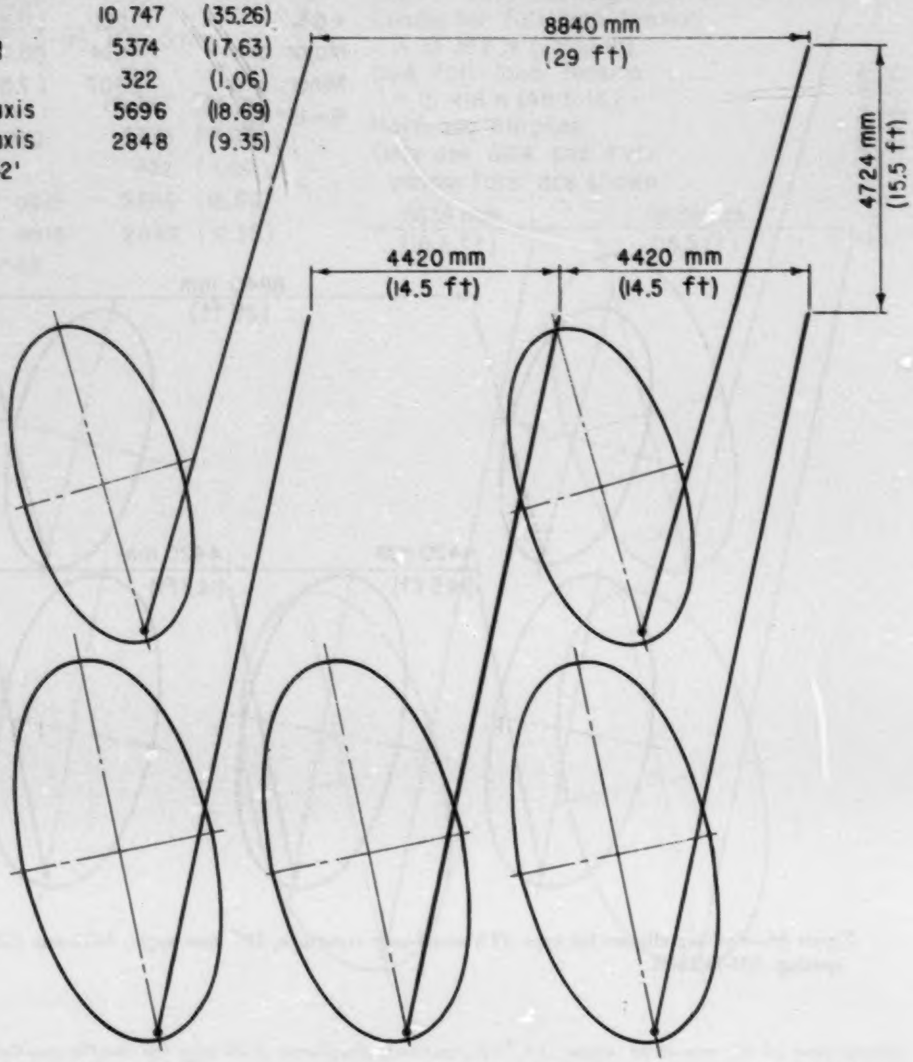


Figure 87.–Half-sag ellipses for type 3TA wood-pole structure, 30° line angle, 4572-mm (15-ft) pole spacing. 104-D-1100.

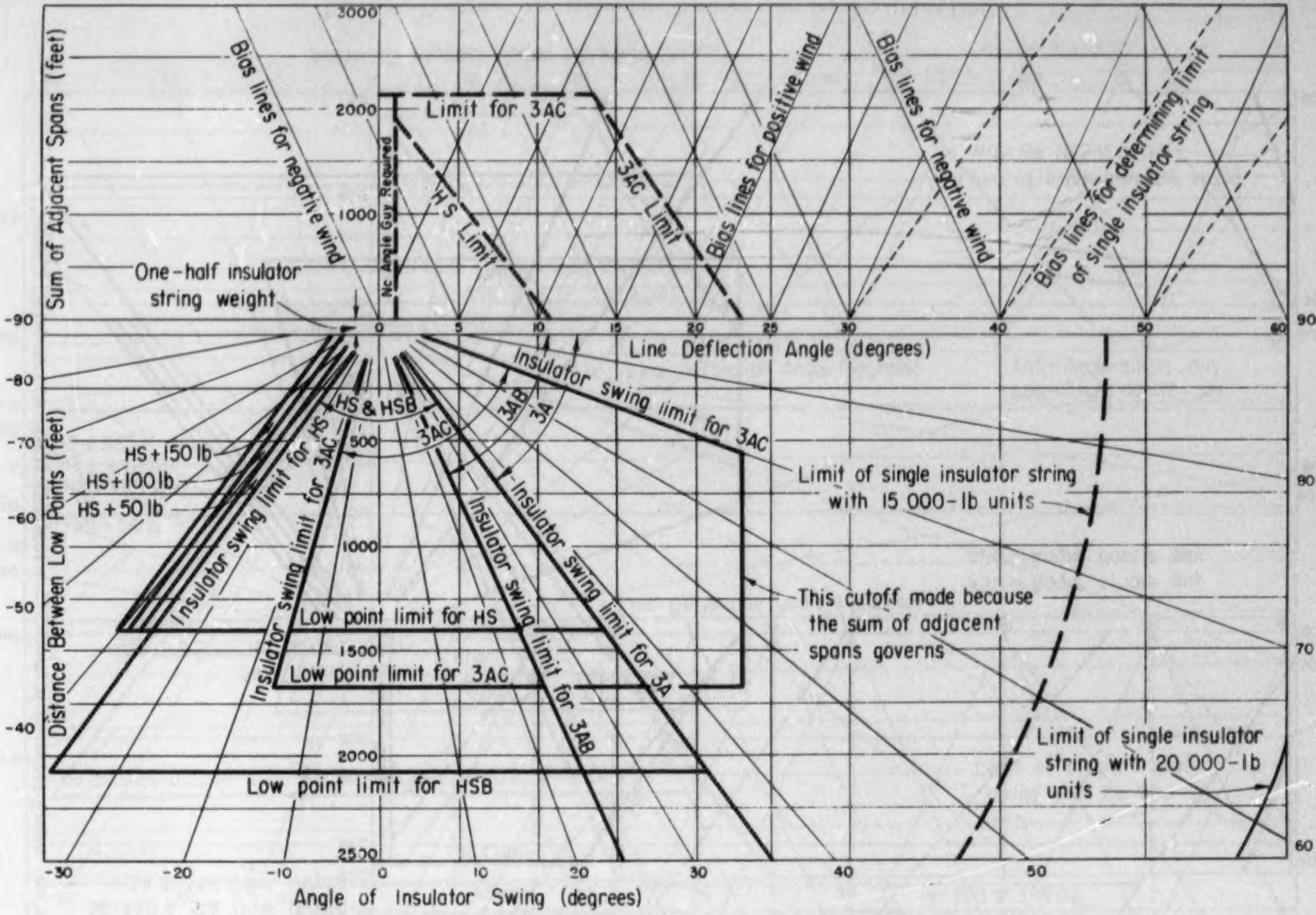


Figure 88.–Instructive example of a wood-structure limitation chart. 104-D-1101.

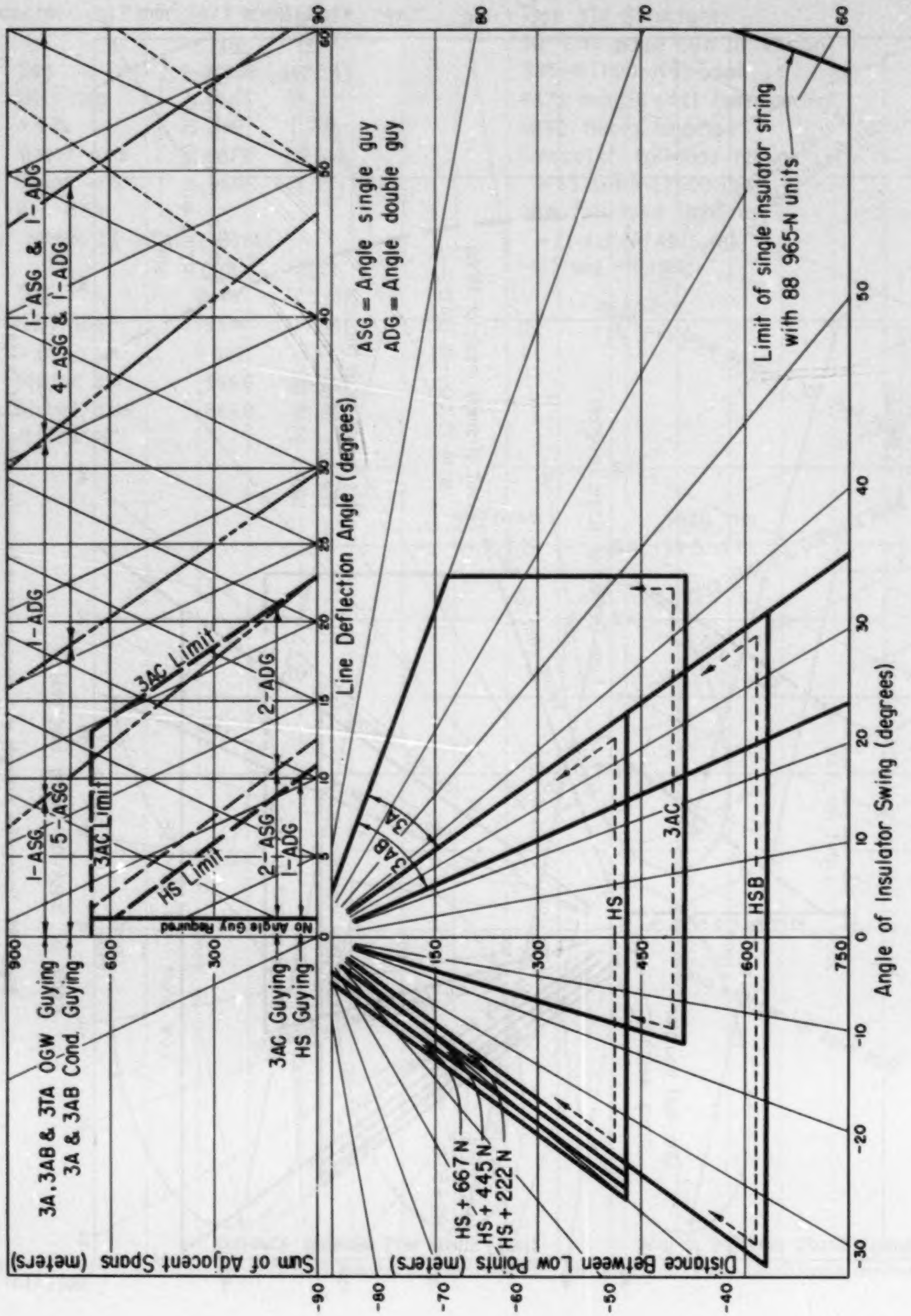


Figure 89.–Example of a wood-structure limitation chart (metric). 104-D-1102.

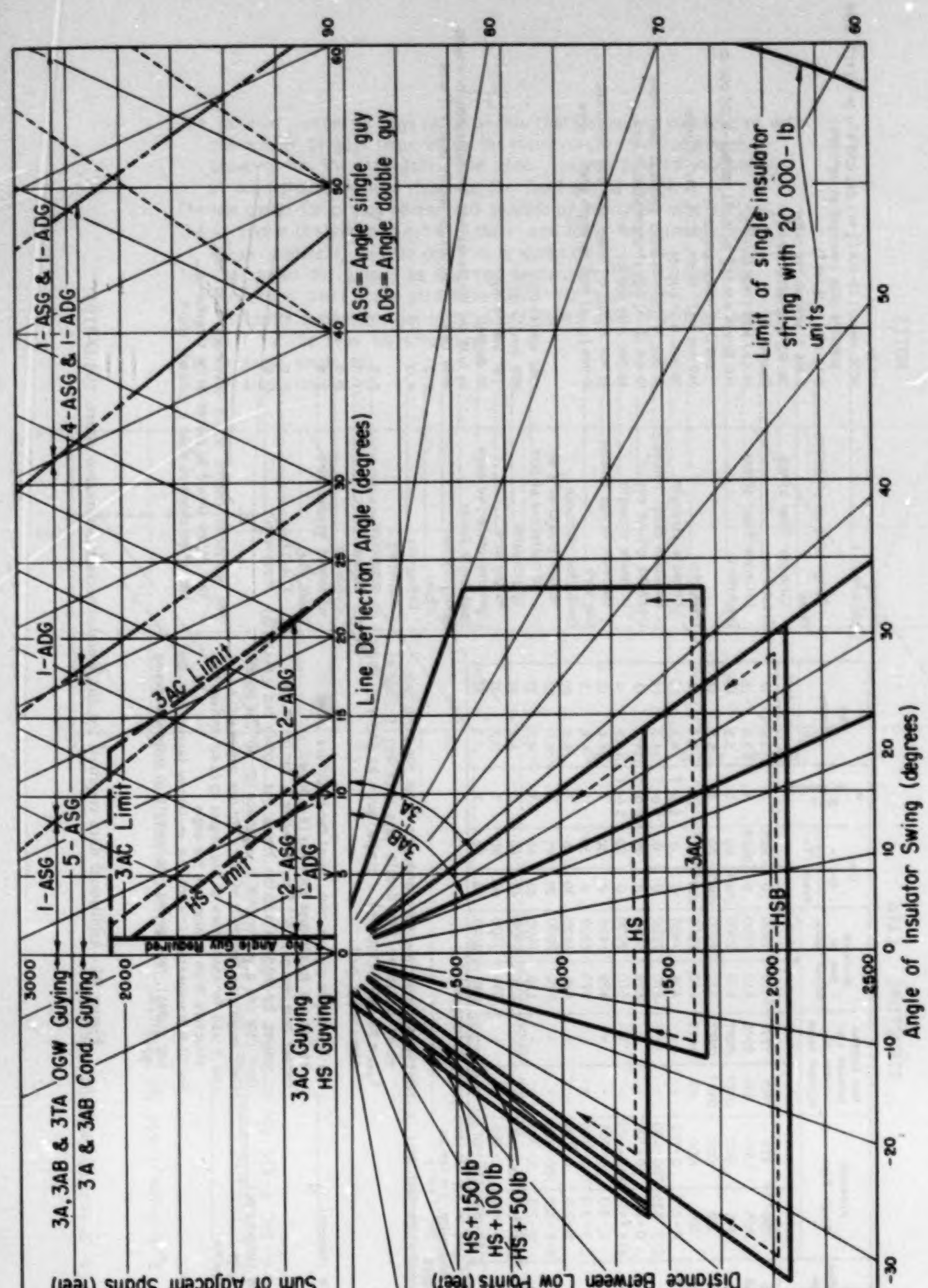


Figure 90.–Example of a wood-structure limitation chart (U.S. customary). 104-D-1103.

STRUCTURE DATA

Structure Type	Allowable Single Spans		Max. Distance Between Low Points in Adjacent Spans		Maximum Sum of Actual Spans		Line Angles		OGW Attachment[2]	Pole Spacing	
	meters	feet	meters	feet	meters	feet	From	To		meters	feet
HS	289	950	425	1395	578	1900	0	chart	S	3.6	12
HSB	305	1000	630	2070	610	2000	0	chart	S	3.6	12
3A	305	1000	chart	chart	610	2000	chart	60	S	5.5	18
3AB	305	1000	chart	chart	610	2000	chart	60	S	5.2	17
3AC	305	1000	510	1675	610	2000	chart	chart	S	4.3	14
3TA[1]	0-213	0-700	-	-	426	1400	0	0	S or T	4.3	14
	213-335	700-1100	-	-	670	2200	0	0	S or T	4.3	14
	0-213	0-700	-	-	426	1400	0	60	S or T	4.3	14
	213-335	700-1100	-	-	670	2200	0	60	S or T	4.3	14
	0-213	0-700	-	-	426	1400	0	30	T	4.6	15
	213-335	700-1100	-	-	670	2200	0	30	T	4.6	15
	0-213	0-700	-	-	426	1400	30	45	T	6.1	20
	213-335	700-1100	-	-	670	2200	30	45	T	6.1	20
	0-213	0-700	-	-	426	1400	45	60	T	8.2	27
	213-335	700-1100	-	-	670	2200	45	60	T	8.2	27
	0-198	0-650	-	-	396	1300	60	90	T	11.3	37
	198-320	650-1050	-	-	640	2100	60	90	T	11.3	37

[1] See figure 94 for standard guying arrangement

[2] S = suspension, T = tension

Line guys

Conductor (tension) ______ One line double guy per conductor. Total for structure would be three line double guys each way (3-LDGEW). $T_{max.}$ = 33 362 N (7500 lb). 1 single guy = 22 800 N (5125 lb) horizontal pull.

OGW (tension) ______ One line double guy per OGW. Total for structure would be two line double guys each way (2-LDGEW). Offset OGW line guys 30° from conductor ℄ for 0°-10° line angles. 22 800 N (5125 lb) times cos 30° = 19 745 N (4438 lb.)

OGW (suspension) ______ Omit OGW line guys for OGW in suspension (0°-60° line angles).

Angle guys ______ Omit angle guys for 0°-1° and 60°-90° line angles.

Conductor ______ Use 3-ASG for conductors on line angles up to 60° to keep the structure from leaning into the angle.

OGW ______ For OGW in suspension (1°-60° line angles) or tension (10°-60° line angles), read guying requirements on suspension guying chart.

NOTES

Voltage ______ 115 kv
Loading ______ NESC Heavy: 13-mm ($\frac{1}{2}$-in) ice, 0.19-kPa (4-lb/ft^2) wind pressure plus constant of -18°C (0°F)
Design wind on structures ______ 0.38 kPa (8 lb/ft^2)
Poles ______ Class 2 western red cedar
Ultimate fiber stress ______ 38.612 MPa (5600 lb/in^2)
Crossarms ______ Douglas fir
Ultimate fiber stress ______ 51.023 MPa (7400 lb/in^2)
Insulators ______ 146 by 254 mm (5$\frac{3}{4}$ by 10 in), 88 964-N (20 000-lb) standard suspension units
Conductor ______ 242 mm^2 (477 kcmil), ACSR, 24/7, Flicker
Ultimate strength ______ 76 509 N (17 200 lb)
Maximum design tension ______ 33 362 N (7500 lb) under full load conditions
Overhead ground wire ______ 10-mm ($\frac{3}{8}$-in) high strength steel, 7 wire
Ultimate strength ______ 48 040 N (10 800 lb)
Maximum design tension ______ 21 418 N (4815 lb) under full load conditions
Guy wire ______ 11-mm ($\frac{7}{16}$-in) high strength steel, 7 wire
Conductor clearance
to pole ground wire or
to centerline of pole ______ 1092 mm (43 in)
to crossarm ______ 889 mm (35 in)
to guy wire ______ 1397 mm (55 in)
Lightning protective angle ______ 30 degrees
Span length limits ______ by half sag ellipse method for suspension structures
Safety factors ______ with 13-mm ($\frac{1}{2}$-in) ice, 0.38-kPa (8-lb/ft) wind
Poles ______ 2.0
Crossarms ______ 4.0
Insulators
suspension ______ 2.5
tension ______ 3.0
Conductor ______ 2.0
Overhead ground wire ______ 2.0
Guy wire
line guys ______ 2.0
transverse ______ 2.67

The appropriate (metric or U.S. customary) data from this figure should be placed on the structure limitation chart to make a complete chart.

Figure 91.–Additional data required for the wood-structure limitation chart. 104-D-1104.

NOTES

The required number of guys noted on this chart should be coordinated with the number of guys required by the standard guying arrangement drawing for the structure type used. The coordinated number of guys should then be shown on the final guying chart.

The line shown for b. may be omitted because of the small area defined.

The H-frame (X-braced) limit and the 1-ADG limit for conductors are about identical, so only one line is shown at f.

The line shown for g. may be omitted because it falls outside the structure limit; use structure limit for guy limit.

Use the same maximum sum of adjacent spans limit for Type 3AC as used for the type HS structures.

ASG = Angle single guy

ADG = Angle double guy

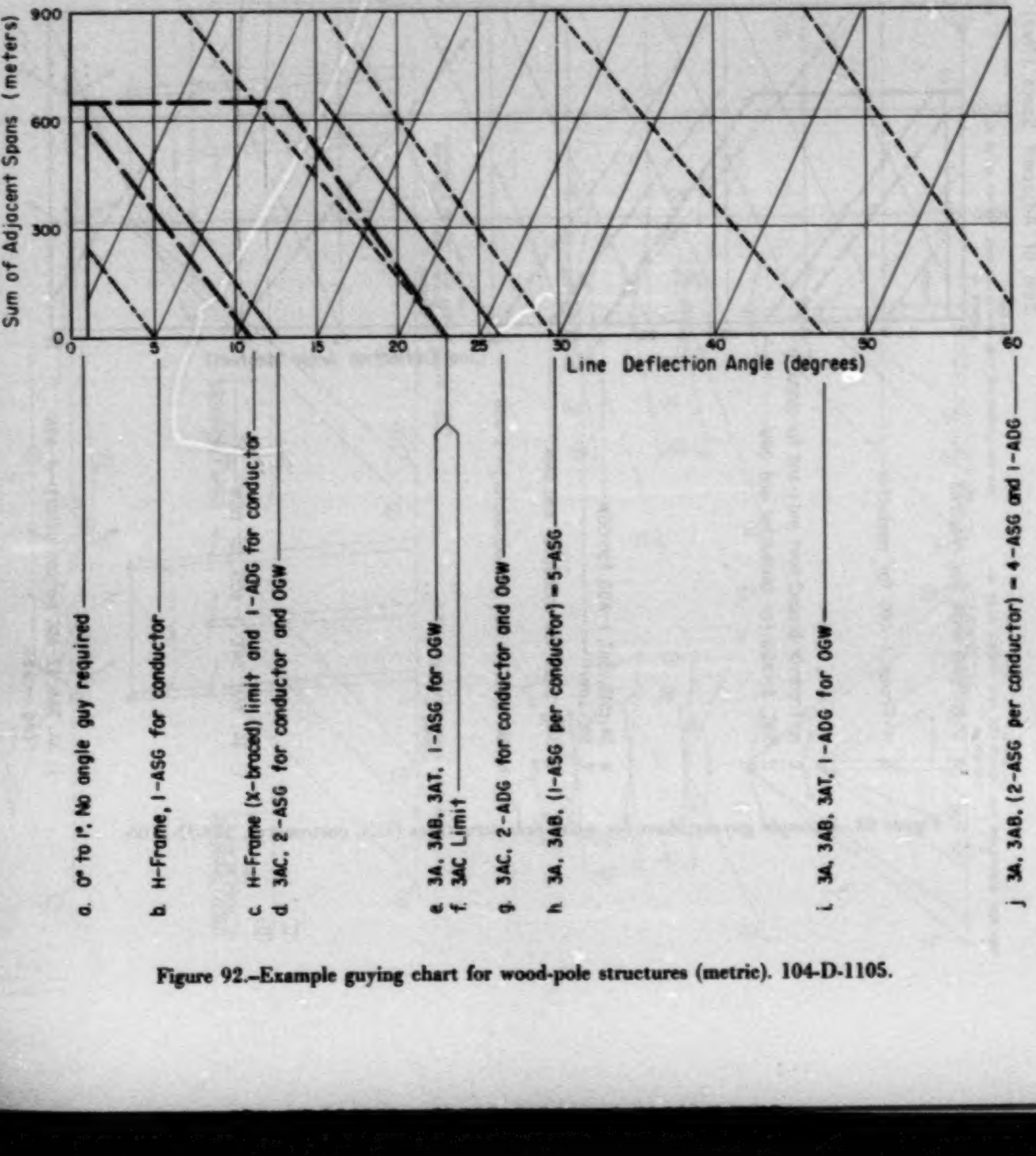


Figure 92.–Example guying chart for wood-pole structures (metric). 104-D-1105.

NOTES

The required number of guys noted on this chart should be coordinated with the number of guys required by the standard guying arrangement drawing for the structure type used. The coordinated number of guys should then be shown on the final guying chart.

The line shown for b. may be omitted because of the small area defined.

The H-frame (X-braced) limit and the 1-ADG limit for conductors are about identical, so only one line is shown at f.

The line shown for g. may be omitted because it falls outside the structure limit; use structure limit for guy limit.

Use the same maximum sum of adjacent spans limit for Type 3AC as used for the Type HS structures.

ASG – Angle single guy

ADG – Angle double guy

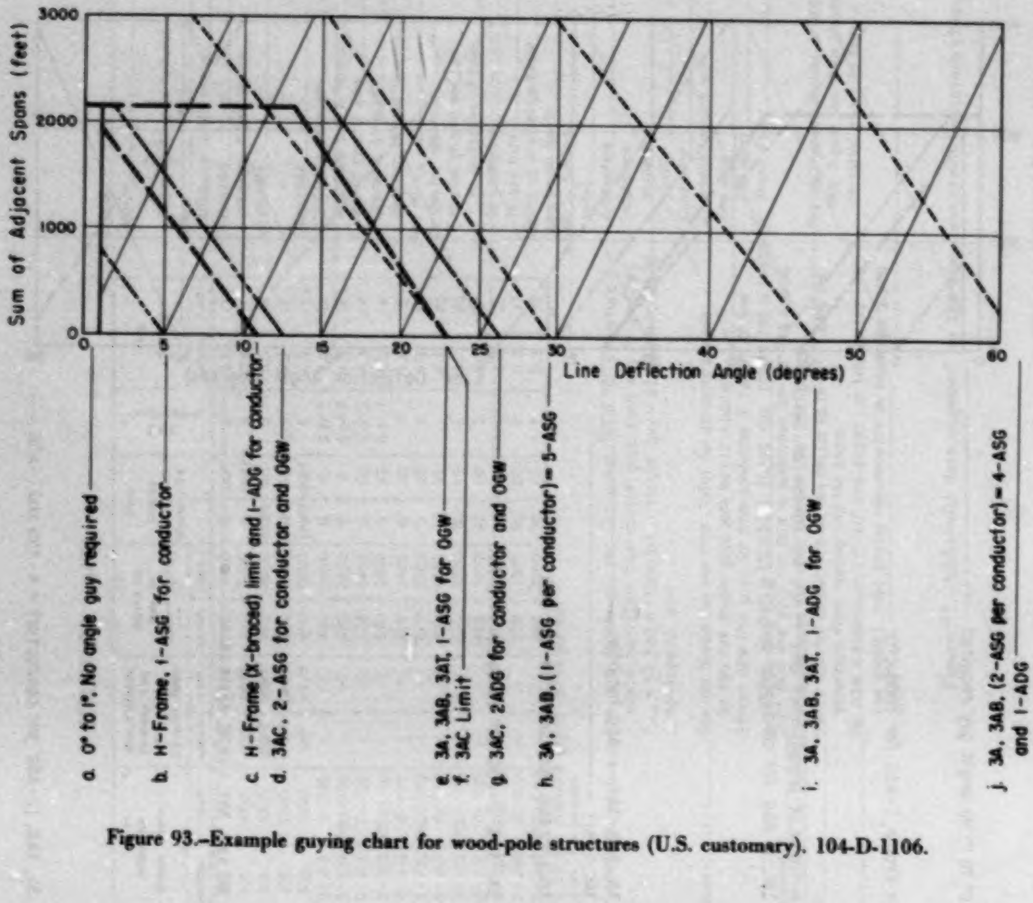


Figure 93.–Example guying chart for wood-pole structures (U.S. customary). 104-D-1106.

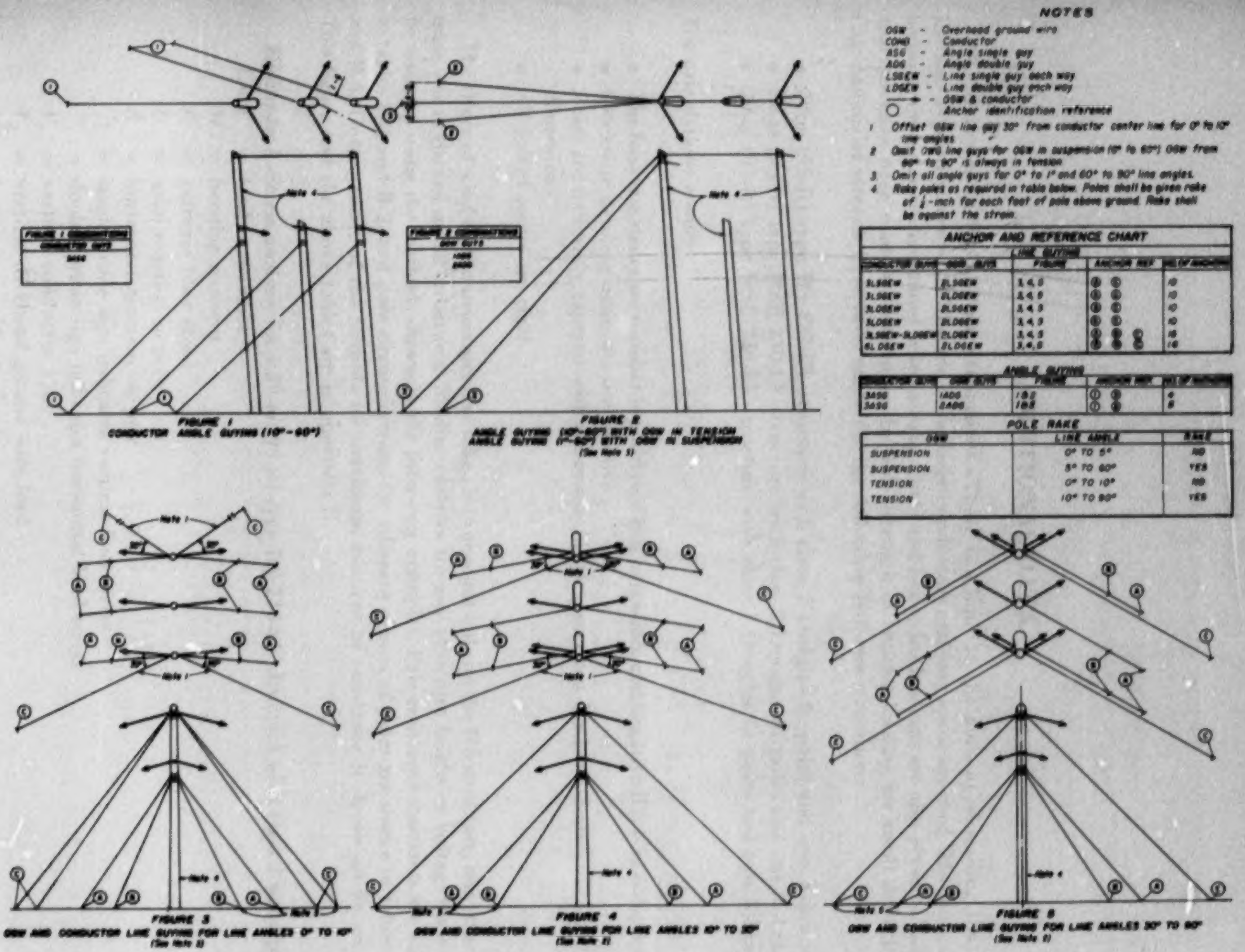


FIGURE 1 COMBINATIONS
CONDUCTOR GUYS
3ASG
FIGURE 2 COMBINATIONS
OGW GUYS
1ADG
2ADG
Note 4
Note 1
Note 2
30°
FIGURE 1
CONDUCTOR ANGLE GUYING (10°-60°)
FIGURE 2
ANGLE GUYING (10°-60°) WITH OGW IN TENSION
ANGLE GUYING (1°-60°) WITH OGW IN SUSPENSION
(See Note 3)
FIGURE 3
OGW AND CONDUCTOR LINE GUYING FOR LINE ANGLES 0° TO 10°
(See Note 2)
FIGURE 4
OGW AND CONDUCTOR LINE GUYING FOR LINE ANGLES 10° TO 30°
(See Note 2)
FIGURE 5
OGW AND CONDUCTOR LINE GUYING FOR LINE ANGLES 30° TO 90°
(See Note 2)

NOTES

OGW - Overhead ground wire
COND - Conductor
ASG - Angle single guy
ADG - Angle double guy
LSGEW - Line single guy each way
LDGEW - Line double guy each way
⟶ - OGW & conductor
○ Anchor identification reference

1 Offset OGW line guy 30° from conductor center line for 0° to 10° line angles.
2 Omit OWG line guys for OGW in suspension (0° to 60°) OGW from 60° to 90° is always in tension
3 Omit all angle guys for 0° to 1° and 60° to 90° line angles.
4 Rake poles as required in table below. Poles shall be given rake of ½-inch for each foot of pole above ground. Rake shall be against the strain.

ANCHOR AND REFERENCE CHART

LINE GUYING

CONDUCTOR GUYS	OGW GUYS	FIGURE	ANCHOR REF	NO. OF ANCHORS
3LSGEW	2LSGEW	3, 4, 5	[illegible]	10
3LSGEW	2LDGEW	3, 4, 5	[illegible]	10
3LDGEW	2LSGEW	3, 4, 5	[illegible]	10
3LDGEW	2LDGEW	3, 4, 5	[illegible]	10
3LSGEW-3LDGEW	2LDGEW	3, 4, 5	[illegible]	16
6LDGEW	2LDGEW	3, 4, 5	[illegible]	16

ANGLE GUYING

CONDUCTOR GUYS	OGW GUYS	FIGURE	ANCHOR REF	NO. OF ANCHORS
3ASG	1ADG	1 & 2	[illegible]	4
3ASG	2ADG	1 & 2	[illegible]	8

POLE RAKE

OGW	LINE ANGLE	RAKE
SUSPENSION	0° TO 5°	NO
SUSPENSION	5° TO 60°	YES
TENSION	0° TO 10°	NO
TENSION	10° TO 90°	YES

Figure 94.–Standard guying arrangement for type 3TA structure. From Dwg. 40-D-6313. 104-D-1139.

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ADDITIONAL DATA

25. Stresses in Wood-Pole Structures.–There is a limit to the amount of loading that the H-frame type structure will withstand when large conductors and long spans are used. This limitation becomes even more pronounced when strong winds and heavy ice loadings are also present. Sample analyses have been made to determine the pole strength in column loading for small deflections. Calculations of stresses have been made for the following H-frame structures:

- 29-m (95-ft) type HS 230-kV structure with class 2 Douglas fir poles and one X-brace
- 29-m (95-ft) type HSB 230-kV structure with class 2 Douglas fir poles and one X-brace
- 29-m (95-ft) type HSB 230-kV structure with class 1 Douglas fir poles and two X-braces

The calculations assume:

- The load in a structure member is positive if it is in tension, and negative if it is in compression
- Clockwise bending moments are positive
- Poles are uniformly tapered with minimum ANSI (American National Standards Institute) dimensions
- All bolted joints are rigid

The effect of wind on the structures was taken into account only on the HS structure, and structure mass was neglected on all structures. Similar analyses for any structure height or voltage class may be made by using the methods shown in the following examples. Pole resistance moments are shown in tables B-1 and B-2, and pole circumferences for different classes of poles are shown in tables B-3 and B-4. Development of the formula for maximum moment of resistance is shown on figure B-4. This figure and the above tables are in appendix B.

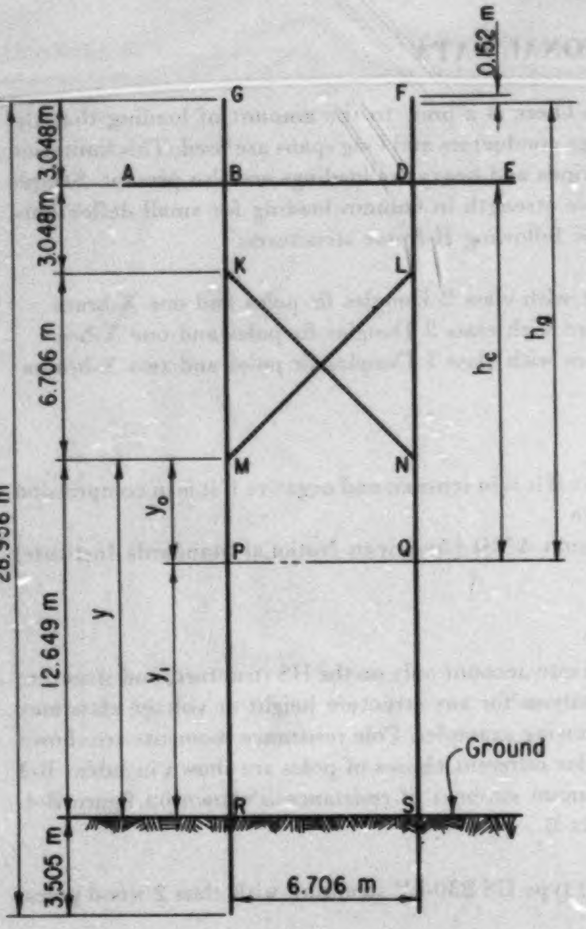
Example 1.–Stress analysis for a 29-m (95-ft) type HS 230-kV structure with class 2 wood poles:

Let L = load in member
M = bending moment
F = extreme fiber stress
U = axial reaction in pole
R = horizontal reaction on pole
$'$ = single prime sign indicates vertical load stress
$''$ = double prime sign indicates horizontal load stress
V_c = vertical conductor load
V_g = vertical overhead ground wire load
H_c = horizontal conductor load

H_g = horizontal overhead ground wire load
P_r = pole resisting moment
LP = distance between low points in adjacent spans
SAS = sum of adjacent spans

Metric

Figure 95 shows the structure outline and other data.



Conductor: 403 mm², ACSR, 45/7
Diameter = 27 mm
0.38-kPa wind on iced (13-mm radial) conductor = 20.07 N/m
Vertical force with 13-mm radial ice = 27.26 N/m

OGW: 10 mm, H.S. Steel, 7-wire
Diameter = 9 mm
0.38-kPa wind on iced (13-mm radial) OGW = 13.23 N/m
Vertical force with 13-mm radial ice = 11.79 N/m

Position	Pole Circumference, mm	P_r, N·m
B or D	718	59 778
K or L	801	82 946
M or N	983	153 411
P or Q	1148	244 634
R or S	1326	376 534

Douglas Fir
Working Stress = 51.02 MPa

Figure 95.–29-m type HS 230-kV structure with class 2 Douglas fir poles (one X-brace). 104-D-1107.

$$V_c = (27.26)(LP) \qquad V_g = (11.79)(LP)$$

$$H_c = (20.07)(SAS/2) \qquad H_g = (13.23)(SAS/2)$$

Vertical loads, $3V_c + 2V_g$, are shared equally by two poles:

$$U_K' = U_L' = U_M' = U_N' = U_P' = U_Q' = U_R' = U_S' = 1.5V_c + V_g$$

For transverse loads H_c and H_g, a plane of inflection PQ exists. The location of the plane is found by:

$$y_0 = \frac{y(P_{rM})}{P_{rR} + P_{rM}} = \frac{(12.649)\,(153\,411)}{376\,534 + 153\,411} = 3.662 \text{ m}$$

$$y_1 = 12.649 - 3.662 = 8.987 \text{ m}$$

The vertical force due to uplift is:

$$V_u = \frac{3H_c(h_c) + 2H_g(h_g) + \text{moment due to wind on poles}}{\text{pole spacing}}$$

Assuming 244-m spans:

$$V_u = \frac{3(20.07)\left(\frac{487.68}{2}\right)(13.416) + 2(13.23)\left(\frac{487.68}{2}\right)(16.312) + 2\left\{\frac{0.383(16.464)^2\,[365.2 + (2)(202.2)]}{6}\right\}}{6.706}$$

$$= 49\,037.60 \text{ N}$$

The uplift force in the windward pole is V_u minus one-half the vertical force of structure, conductor, and overhead ground wire.

The downward force in the leeward pole is V_u plus one-half the vertical force of structure, conductor, and overhead ground wire.

The force in the X-brace is $0.5\,V_u/\sin\theta$.

For braces installed at 45°, $0.5\,V_u\;0.707 = 0.707\,V_u$.

Pole bending moments are:

$$\text{At } K, M_K = (1.5H_c)\,(3.048) + H_g(5.944) + \text{moment due to wind on pole}$$

$$M_K = 4.572(20.07)\,(243.84) + 5.944(13.23)\,(243.84) + \frac{0.383(6.096)^2\,[254.8 + (2)\,(202.2)]}{6} = 43\,114 \text{ N·m}$$

$$\text{At } M, M_M = (1.5H_c + H_g)y_0 + \text{moment due to wind on pole}$$

$$M_M = [(1.5)\,(20.07) + 13.23]\,(243.8)\,(3.662) + \frac{0.383(12.802)^2\,[312.7 + (2)\,(202.2)]}{6} = 46\,291 \text{ N·m}$$

$$\text{At } R, M_R = (1.5H_c + H_g)y_1 + \text{moment due to wind on pole}$$

$$M_R = [(1.5)(20.07) + 13.23]\ (243.8)\ (8.987)$$

$$+ \frac{0.383(25.451)^2\ [421.9 + (2)\ (202.2)]}{6} = 129\ 114\ \text{N·m}$$

Crossarm strength:[1]

For a 79- by 267-mm laminated arm, the ultimate fiber stress $S = 13.79$ MPa:

$$W_v = \frac{Sbd^2}{6L}$$

where:

W_v = ultimate vertical load, N
b = horizontal thickness of arm, mm
d = vertical thickness of arm, mm
L = length of arm to load (lever arm), mm

$$W_v = \frac{13.79(79)\ (267)^2}{6(3352.8)} = 3861 \text{ N or } 7722 \text{ N for a double arm}$$

For the given conductor, the vertical force is 27.26 N/m (with 13-mm radial ice).

Allowable distance between low points is 7722/27.26 = 283.272 m.

U.S. Customary
Figure 96 shows the structure outline and other data.

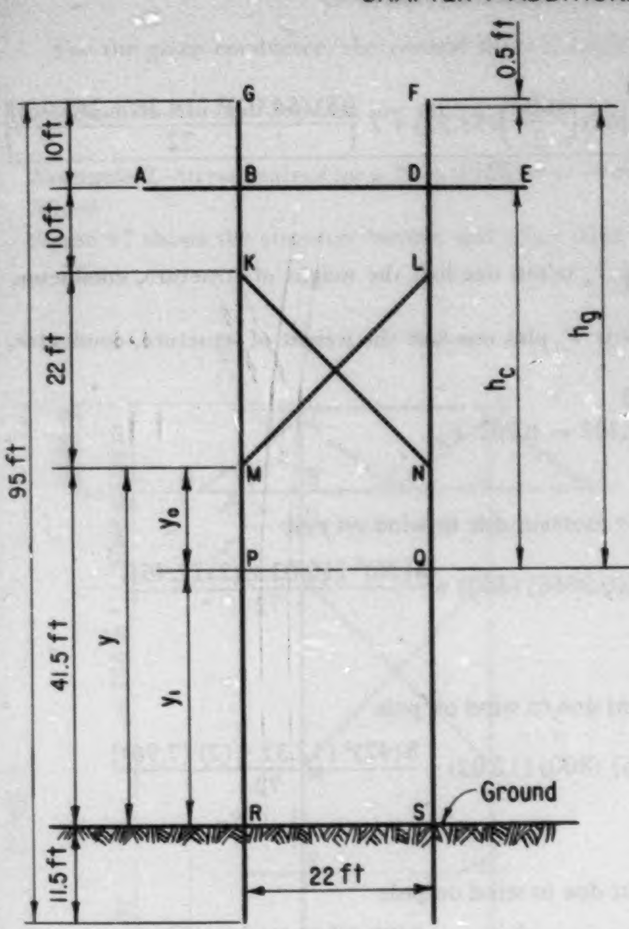
$$V_c = (1.8682)(\text{LP}) \qquad V_g = (0.8079)(\text{LP})$$
$$H_c = (1.3754)(\text{SAS}/2) \qquad H_g = (0.9066)(\text{SAS}/2)$$

Vertical loads, $3V_c + 2V_g$, are shared equally by two poles:

$$U_K' = U_L' = U_M' = U_N' = U_P' = U_Q' = U_R' = U_S' = 1.5V_c + V_g$$

---

[1] **Standard Specifications for Structural Glued Laminated Douglas Fir (Coast Region) Timber (West Coast Lumbermen's Association), table II, combination E, shows this ultimate fiber stress is 2000 lb/in² (13.79 MPa) for a 3-1/8- by 10-1/2-in (79- by 267-mm) laminated crossarm.**



Conductor: 795 kcmil, ACSR, 45/7
Diameter = 1.063 in
8-lb/ft² wind on iced (½-in radial) conductor = 1.3754 lb/ft
Vertical force with ½-in radial ice = 1.8682 lb/ft

OGW: ⅜-in H.S. steel, 7-wire
Diameter = 0.360 in
8-lb/ft² wind on iced (½-in radial) OGW = 0.9066 lb/ft
Vertical force with ½-in radial ice = 0.8079 lb/ft

Position	Pole Circumference, in	P_r, lb·ft
B or D	28.26	44 100
K or L	31.52	61 059
M or N	38.69	113 244
P or Q	45.20	180 421
R or S	52.19	277 731

Douglas Fir
Working stress = 7400 lb/in²

Figure 96.–95-ft type HS 230-kV structure with class 2 Douglas fir poles (one X-brace). 104-D-1108.

For transverse loads H_c and H_g, a plane of inflection PQ exists. The location of the plane is found by:

$$y_0 = \frac{y(P_{rM})}{P_{rR} + P_{rM}} = \frac{(41.5)\ (113\ 244)}{277\ 731 + 113\ 244} = 12.02\ \text{ft}$$

$$y_1 = 41.5 - 12.02 = 29.48\ \text{ft}$$

The vertical force due to the uplift is:

$$V_u = \frac{3H_c(h_c) + 2H_g(h_g) + \text{moment due to wind on poles}}{\text{pole spacing}}$$

Assuming 800-ft spans:

$$V_u = \frac{3(1.3754)\left(\frac{1600}{2}\right)(44.02) + 2(0.9066)\left(\frac{1600}{2}\right)(53.52) + 2\left\{\frac{(8)(54.02)^2\,[14.38 + 2(7.96)]}{72}\right\}}{22}$$

$$= 11\,026.87 \text{ lb}$$

The uplift force in the windward pole is V_u minus one-half the weight of structure, conductor, and overhead ground wire.

The downward force in the leeward pole is V_u plus one-half the weight of structure, conductor, and overhead ground wire.

The force in the X-brace is $0.5\,V_u/\sin\theta$.

For braces installed at 45°, $0.5\,V_u/0.707 = 0.707\ V_u$

Pole bending moments are:

At K, $M_K = (1.5H_c)(10) + H_g(19.5)$ + moment due to wind on pole

$$M_K = 15(1.3752)(800) + 19.5(0.9066)(800) + \frac{8(20)^2\,[10.03 + (2)(7.96)]}{72}$$

$$= 31\,799 \text{ lb}\cdot\text{ft}$$

At M, $M_M = (1.5H_c + H_g)y_0$ + moment due to wind on pole

$$M_M = [(1.5)(1.3752) + 0.9066](800)(12.02) + \frac{8(42)^2\,[12.31 + (2)(7.96)]}{72}$$

$$= 34\,087 \text{ lb}\cdot\text{ft}$$

At R, $M_R = (1.5H_c + H_g)y_1$ + moment due to wind on pole

$$M_R = [(1.5)(1.3752) + 0.9066](800)(12.02) + \frac{8(83.5)^2\,[16.61 + (2)(7.96)]}{72}$$

$$= 95\,231 \text{ lb}\cdot\text{ft}$$

Crossarm strength:

For a 3-1/8- by 10-1/2-in laminated arm, the ultimate fiber stress $S =$ 2000 lb/in².

$$W_v = \frac{Sbd^2}{6L}$$

where:

W_v = ultimate vertical load, lb
b = horizontal thickness of arm, in
d = vertical thickness of arm, in
L = length of arm to load (lever arm), in

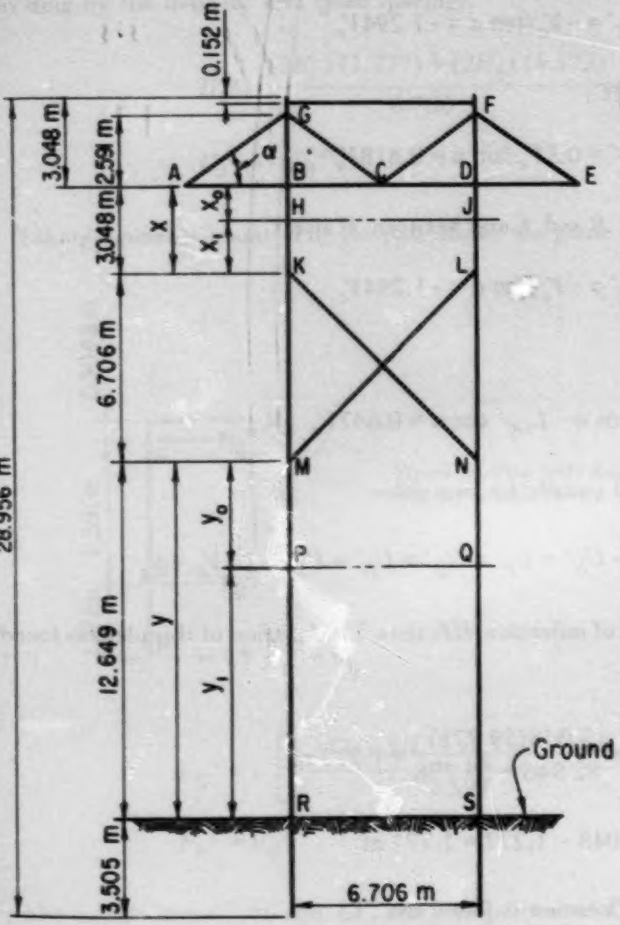
$$W_v = \frac{2000(3.125)(10.5)^2}{6(132)} = 870 \text{ lb or } 1740 \text{ lb for a double arm}$$

For the given conductor, the vertical force is 1.8682 lb/ft (with 1/2-in radial ice).

Allowable distance between low points is 1740/1.8682 = 931 ft.

Example 2.*–Stress analysis for a 29-m (95-ft) type HSB 230-kV structure with class 2 wood poles:** ***Metric

Figure 97 shows the structure outline and other data. Using the nomenclature from example 1,



Conductor: 403 mm^2, ASCR, 45/7
Diameter – 27 mm
0.38-kPa wind on iced (13-mm radial) conductor – 20.07 N/m
Vertical force with 13-mm radial ice – 27.26 N/m

OGW: 10 mm, H.S. Steel, 7-wire
Diameter – 9 mm
0.38-kPa wind on iced (13-mm radial) OGW – 13.23 N/m
Vertical force with 13-mm radial ice – 11.79 N/m

Position	Pole Circumference, mm	P_r, N·m
B or D	718	59 778
K or L	801	82 946
M or N	983	153 411
P or Q	1148	244 634
R or S	1326	376 534

Douglas Fir
Working Stress – 51.02 MPa

$$\tan\alpha = \frac{2.591}{3.353} = 0.7727$$

$$\sin\alpha = 0.6114$$

$$\cos\alpha = 0.7913$$

$$\alpha = 37^\circ 41'$$

Figure 97.–29-m type HSB 230-kV structure with class 2 Douglas fir poles (one X-brace). 104-D-1109.

$$V_c = (27.26)(\text{LP}) \qquad V_g = (11.79)(\text{LP})$$
$$H_c = (20.07)(\text{SAS}/2) \qquad H_g = (13.23)(\text{SAS}/2)$$

Load in adjustable braces *AG* and *EF*:

$$L_{AG}' = L_{EF}' = V_c/\sin a = 1.635 V_c$$

Compression load in crossarm:

$$L_{AB}' = L_{DE}' = -V_c/\tan a = -1.294 V_c$$

Load in nonadjustable braces *GC* and *FC*:

$$L_{GC}' = L_{FC}' = 0.5 V_c/\sin a = 0.818 V_c$$

Compressive force in crossarm between *B* and *C* and between *D* and *C*:

$$L_{BC}' = L_{DC}' = -V_c/\tan a = -1.294 V_c$$

Load in crosstie *GF*:

$$L_{GF}' = L_{AG}' \cos a - L_{GC}' \cos a = 0.647 V_c$$

Vertical loads, $3V_c$ and $2V_g$, are shared equally by two poles:

$$U_H' = U_J' = U_K' = U_L' = U_M' = U_N' = U_P' = U_Q' = U_R' = U_S' = 1.5V_c + V_g$$

For transverse loads H_c and H_g, a plane of inflection *HJ* exists. The location of this plane is found by:

$$x_0 = \frac{x(P_{rB})}{P_{rK} + P_{rB}} = \frac{3.048(59\,778)}{82\,946 + 59\,778} = 1.277 \text{ m}$$

$$x_1 = x - x_0 = 3.048 - 1.277 = 1.771 \text{ m}$$

A plane of inflection *PQ* also exists. Its location is found by:

$$y_0 = \frac{y(P_{rM})}{P_{rR} + P_{rM}} = \frac{12.649(153\,411)}{376\,534 + 153\,411} = 3.662 \text{ m}$$

$$y_1 = y - y_0 = 12.649 - 3.662 = 8.987 \text{ m}$$

When position of zero moment is known, the structure may be separated into parts and each part considered separately.

Horizontal wind forces on conductors and overhead ground wires are resisted equally by each pole at the points of zero moment.

$$R_H'' = R_J'' = R_P'' = R_Q'' = -\ 1.5H_c - H_g$$

Axial reaction at *J* caused by horizontal wind force is found by taking moments about *H* and dividing by the moment arm (pole spacing).

$$U_J'' = \frac{(3H_c)\,(1.277) + (2H_g)\,(4.173)}{6.706} = 0.571H_c + 1.244H_g$$

$$U_J'' = -\,U_H''$$

Taking moments about *B* in the pole above the plane of inflection (fig. 98), gives the force F_G'':

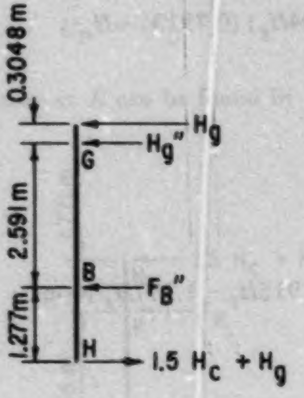


Figure 98.–Free body diagram of pole above plane of inflection and to the crosstie (metric example 2).

$$F_G'' = -\left[\frac{1.277(1.5H_c + H_g) + 2.896H_g}{2.591}\right] = -0.739H_c - 1.611H_g$$

$$F_F'' = F_G''$$

The outside braces, *AG* and *EF*, carry 10 percent of F_G'' and F_H'' while the inside braces, *CG* and *CF*, carry 90 percent. Load on the inner braces *CG* and *CF* is:

$$L_{CG}'' = \frac{0.9F_G''}{\cos a} = \frac{0.9(-0.739H_c - 1.611H_g)}{0.7913} = -0.841H_c - 1.832H_g$$

$$L_{CF}'' = -\,L_{CG}''$$

The load in the outer braces *AG* and *EF* is:

$$L_{AG}'' = \frac{-0.1F_G''}{\cos a} = \frac{-0.1(-0.739H_c - 1.611H_g)}{0.7913} = 0.0934H_c + 0.2036H_g$$

$$L_{EF}'' = -L_{AG}''$$

The load in the crossarm portions *BC* and *CD* is:

$$L_{BC}'' = (-L_{CG}'')\cos a + 0.5H_c = -(-0.841H_c - 1.832H_g)(0.7913) + 0.5H_c)$$

$$= 1.165H_c + 1.448H_g$$

$$L_{BC}'' = -L_{CD}''$$

The load in the crossarm portions *AB* and *DE* is:

$$L_{AB}'' = -(L_{AG}''\cos a + H_c) = -(0.0934H_c + 0.204H_g)(0.7913) - H_c$$

$$= -1.074H_c - 0.161H_g$$

$$L_{AB}'' = -L_{DE}''$$

The moment at *B* and *D* is given by:

$$M_D'' = -x_0(1.5H_c + H_g) = -1.277(1.5H_c + H_g) = -1.915H_c - 1.277H_g \text{ N}\cdot\text{m}$$

$$M_B'' = M_D''$$

For the portion of the pole between the planes of inflection, the moment at *K* and *L* is:

$$M_K'' = x_1(1.5H_c + H_g) = 1.771(1.5H_c + H_g) = 2.657H_c + 1.771H_g \text{ N}\cdot\text{m}$$

$$M_L'' = M_K''$$

The area of the pole at *K* and *L*, excluding the 23.8-mm-diameter hole for mounting the X-brace is:

$$A_K = \frac{\pi D^2}{4} - 23.8D = \frac{\pi}{4}(254.84)^2 - 23.8(254.84) = 51\,006 - 6065 = 44\,941 \text{ mm}^2$$

$$A_L = A_K$$

The section modulus at *K* and *L* is:

$$Z_K = \frac{\pi D^3}{32} - \frac{23.8D^2}{6} = \frac{\pi}{32}(254.84)^3 - \frac{23.8}{6}(254.84)^2 = 1\,624\,810 - 257\,609$$

$$= 1\,367\,201 \text{ mm}^3$$

$$Z_L = Z_K$$

The horizontal reaction in the poles at *P* and *Q* is:

$$R_P'' = R_Q'' = -1.5H_c - H_g$$

The axial reaction in the poles at *P* and *Q* is:

$$U_Q'' = \frac{3H_c + 2H_g}{6.706}(12.139) + 0.571H_c + 1.244H_g = 6.002H_c + 4.864H_g$$

$$U_P'' = -U_Q''$$

The force at *K* can be found by taking moments about point *M* (fig. 99):

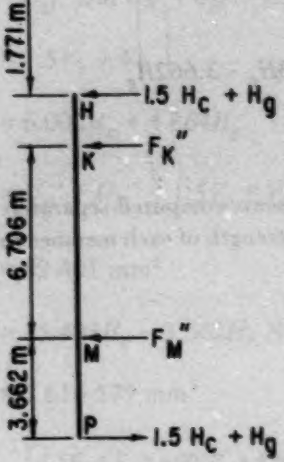


Figure 99.–Free body diagram of pole between planes of inflection (metric example 2).

$$F_K'' = -\left[\frac{8.477(1.5H_c + H_g) + 3.662(1.5H_c + H_g)}{6.706}\right] = -2.715H_c - 1.813H_g$$

$$F_K'' = -F_M''$$

The force in X-braces *KN* and *LM* is:

$$L_{KN}'' = -\left(\frac{2.715H_c + 1.813H_g}{\sin 45^\circ}\right) = -3.840H_c - 2.564H_g$$

$$L_{KN}'' = -L_{LM}''$$

The net area of the pole (less the X-brace mounting hole) at *M* and *N* is:

$$A_M = \frac{\pi D^2}{4} - 23.8D = \frac{\pi}{4}(312.80)^2 - 23.8(312.80) = 76\,846 - 7445 = 69\,401 \text{ mm}^2$$

$$A_M = A_N$$

The section modulus at *M* and *N* is:

$$Z_M = \frac{\pi D^3}{32} - \frac{23.8D^2}{6} = \frac{\pi}{32}(312.80)^3 - \frac{23.8}{6}(312.80)^2 = 3\,004\,693 - 388\,114$$

$$= 2\,616\,579 \text{ mm}^3$$

$$Z_M = Z_N$$

Taking moments about point *M* (fig. 99):

$$M_M'' = -3.662(1.5H_c + H_g) = -5.493H_c - 3.662H_g$$

$$M_M'' = M_N''$$

By superposition, the values of the forces and bending moments computed separately for vertical and horizontal loading can be combined for total loading. The strength of each member can be divided by its respective total load and safety factors tabulated.

Stress in the poles is:

At point *L*:

$$S_L = \frac{P}{A} \pm \frac{M}{Z}$$

$$S_L = \frac{U_L}{A_L} \pm \frac{M_L}{Z_L}$$

where:

$$U_L'' = U_J'' + 0.707L_{LM}'' \text{ and } U_L = U_L' + U_L''$$

$$U_L'' = 0.571H_c + 1.244H_g + 0.707(3.840H_c + 2.564H_g) = 3.286H_c + 3.057H_g$$

$$U_L' = 1.5V_c + V_g$$

$$U_L = U_L' + U_L'' = 1.5V_c + V_g + 3.286H_c + 3.057H_g$$

$$A_L = 44\,941 \text{ mm}^2$$

$$M_L'' = 2.657H_c + 1.771H_g \text{ N}\cdot\text{m}$$

$$Z_L = 1\,367\,201 \text{ mm}^3$$

$$S_L = \left[\frac{1.5V_c + V_g + 3.286H_c + 3.057H_g}{44\,941 \text{ mm}^2} + \left(\frac{2.657H_c + 1.771H_g}{1\,367\,201 \text{ mm}^3}\right)\left(\frac{1000 \text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2 \text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

At point N:

$$S_N = \frac{U_N}{A_N} \pm \frac{M_N}{Z_N}$$

where:

$$U_N'' = U_Q'' \text{ and } U_N = U_N' + U_N''$$

$$U_N' = 1.5V_c + V_g$$

$$U_N'' = 6.002H_c + 4.864H_g$$

$$U_N = U_N' + U_N'' = 1.5V_c + V_g + 6.002H_c + 4.864H_g$$

$$A_N = 69\,401 \text{ mm}^2$$

$$M_N'' = -5.493H_c - 3.662H_g \text{ N}\cdot\text{m}$$

$$Z_N = 2\,616\,579 \text{ mm}^3$$

$$S_N = \left[\frac{1.5V_c + V_g + 6.002H_c + 4.864H_g}{69\,401} + \left(\frac{5.493H_c + 3.662H_g}{2\,616\,579}\right)\left(\frac{1000 \text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2 \text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

Adjustable braces *AG* and *EF*:

	$L_{AG}' = 1.635\,V_c$	$L_{AG}'' = 0.0934H_c + 0.2036H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
183-m Spans, LP = 366 m V_c = 9977 N V_g = 4315 N H_c = 3673 N H_g = 2421 N	16 312	343.06 + 492.92 = 836	17 148 N
213-m Spans, LP = 426 m V_c = 11 613 N V_g = 5 023 N H_c = 4 275 N H_g = 2 818 N	18 987	399.29 + 573.74 = 973	19 960 N
244-m Spans, LP = 488 m V_c = 13 303 N V_g = 5 754 N H_c = 4 897 N H_g = 3 228 N	21 750	457.38 + 657.22 = 1115	22 865 N
274-m Spans, LP = 548 m V_c = 14 938 N V_g = 6 461 N H_c = 5 499 N H_g = 3 625 N	24 424	513.61 + 738.05 = 1252	25 676 N
305-m Spans, LP = 610 m V_c = 16 629 N V_g = 7 192 N H_c = 6 121 N H_g = 4 035 N	27 188	571.70 + 821.53 = 1393	28 581 N
335-m Spans, LP = 670 m V_c = 18 264 N V_g = 7 899 N H_c = 6 723 N H_g = 4 432 N	29 862	627.93 + 902.36 = 1530	31 392 N
366-m Spans, LP = 732 m V_c = 19 954 N V_g = 8 630 N H_c = 7 346 N H_g = 4 842 N	32 625	686.12 + 985.83 = 1672	34 297 N
396-m Spans, LP = 792 m V_c = 21 590 N V_g = 9 338 N H_c = 7 948 N H_g = 5 239 N	35 300	742.34 + 1066.66 = 1809	37 109 N

Adjustable braces *AG* and *EF* –Continued

	$L_{AG}' = 1.635\ V_c$	$L_{AG}'' = 0.0934\ H_c + 0.2036\ H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
427-m Spans, LP = 854 m	38 063	800.44 + 1150.14 = 1951	40 014 N

V_c = 23 280 N
V_g = 10 069 N
H_c = 8 570 N
H_g = 5 649 N

Nonadjustable braces *GC* and *FC* :

Spans, m	LP, m	$L_{GC}' = 0.818\ V_c$, N	$L_{GC}'' = 0.841\ H_c + 1.832\ H_g$, N	$L_{GC} = L_{GC}' + L_{GC}''$ N
183	366	8 161	3088.99 + 4 435.27 = 7 524	15 685
213	426	9 499	3595.27 + 5 162.58 = 8 758	18 257
244	488	10 882	4118.38 + 5 913.70 = 10 032	20 914
274	548	12 219	4624.66 + 6 641.00 = 11 266	23 485
305	610	13 603	5147.76 + 7 392.12 = 12 540	26 143
335	670	14 940	5654.04 + 8 119.42 = 13 773	28 713
366	732	16 322	6177.99 + 8 870.54 = 15 049	31 371
396	792	17 661	6684.27 + 9 597.85 = 16 282	33 943
427	854	19 043	7207.37 + 10 348.97 = 17 556	36 599

Crosstie *GF* :

Spans, m	LP, m	$L_{GF}' = 0.647\ V_c$, N
183	366	6 455
213	426	7 514
244	488	8 607
274	548	9 665
305	610	10 759
335	670	11 817
366	732	12 910
396	792	13 969
427	854	15 062

Crossarms *AB* and *DE* (compressive):

Spans, m	LP, m	$L_{AB}' = -1.294\ V_c$, N	$L_{AB}'' = -1.074\ H_c - 0.161\ H_g$, N	$L_{AB} = L_{AB}' + L_{AB}''$, N
183	366	−12 910	−3944.80 − 389.78 = −4 335	−17 245
213	426	−15 027	−4591.35 − 453.70 = −5 045	−20 072
244	488	−17 214	−5259.38 − 519.71 = −5 779	−22 993
274	548	−19 330	−5905.93 − 583.63 = −6 490	−25 820
305	610	−21 518	−6573.95 − 649.64 = −7 224	−28 742
335	670	−23 634	−7220.50 − 713.55 = −7 934	−31 568
366	732	−25 820	−7889.60 − 779.56 = −8 669	−34 489
396	792	−27 937	−8536.15 − 843.48 = −9 380	−37 317
427	854	−30 124	−9204.18 − 909.49 = −10 114	−40 238

Crossarms *BC* and *CD* (compressive):

Spans, m	LP, m	$L_{CD}' = -1.294\,V_c$, N	$L_{CD}'' = -1.165\,H_c - 1.448\,H_g$, N	$L_{CD} = L_{CD}' + L_{CD}''$, N
183	366	−12 910	−4279.05 − 3505.61 = −7 785	−20 695
213	426	−15 027	−4980.38 − 4080.46 = −9 061	−24 088
244	488	−17 214	−5705.01 − 4674.14 = −10 379	−27 593
274	548	−19 330	−6406.34 − 5249.00 = −11 655	−30 985
305	610	−21 518	−7130.97 − 5842.68 = −12 974	−34 492
335	670	−23 634	−7832.30 − 6417.54 = −14 250	−37 884
366	732	−25 820	−8558.09 − 7011.22 = −15 569	−41 389
396	792	−27 937	−9259.42 − 7586.07 = −16 845	−44 782
427	854	−30 124	−9984.05 − 8179.75 = −18 163	−48 287

X-braces *KN* and *LM*:

Spans, m	LP, m	$L_{KN}'' = -3.840\,H_c - 2.564\,H_g$, N
183	366	−14 104 − 6 207 = −20 311
213	426	−16 416 − 7 225 = −23 641
244	488	−18 735 − 8 277 = −27 012
274	548	−21 112 − 9 295 = −30 407
305	610	−23 505 − 10 346 = −33 851
335	670	−25 816 − 11 364 = −37 180
366	732	−28 209 − 12 415 = −40 624
396	792	−30 520 − 13 433 = −43 953
427	854	−32 909 − 14 484 = − 47 383

Poles (at point *L*):

$$S_L = \left[\frac{1.5V_c + V_g + 3.286H_c + 3.057H_g}{44\,941\text{ mm}^2} + \left(\frac{2.657H_c + 1.771H_g}{1\,367\,201\text{ mm}^3}\right)\left(\frac{1000\text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2\text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

183-m spans, 366-m LP

$$S_L = \left[\frac{1.5(9977) + 4315 + 3.286(3673) + 3.057(2421)}{44\,941} + \frac{2.657(3673) + 1.771(2421)}{1367.201}\right](1000) = 11\,136\text{ kPa}$$

213-m spans, 426-m LP

$$S_L = \left[\frac{1.5(11\,613) + 5023 + 3.286(4275) + 3.057(2818)}{44\,941} + \frac{2.657(4275) + 1.771(2818)}{1367.201}\right](1000) = 12\,962\text{ kPa}$$

244-m spans, 488-m LP

$$S_L = \left[\frac{1.5(13\,303) + 5754 + 3.286(4897) + 3.057(3228)}{44\,941} + \frac{2.657(4897) + 1.771(3228)}{1367.201}\right](1000) = 14\,848\text{ kPa}$$

274-m spans, 548-m LP

$$S_L = \left[\frac{1.5(14\,938) + 6461 + 3.286(5499) + 3.057(3625)}{44\,941} + \frac{2.657(5499) + 1.771(3625)}{1367.201}\right](1000) = 16\,673 \text{ kPa}$$

305-m spans, 610-m LP

$$S_L = \left[\frac{1.5(16\,629) + 7192 + 3.286(6121) + 3.057(4035)}{44\,941} + \frac{2.657(6121) + 1.771(4035)}{1367.201}\right](1000) = 18\,559 \text{ kPa}$$

335-m spans, 670-m LP

$$S_L = \left[\frac{1.5(18\,264) + 7899 + 3.286(6723) + 3.057(4432)}{44\,941} + \frac{2.657(6723) + 1.771(4432)}{1367.201}\right](1000) = 20\,385 \text{ kPa}$$

366-m spans, 732-m LP

$$S_L = \left[\frac{1.5(19\,954) + 8630 + 3.286(7346) + 3.057(4842)}{44\,941} + \frac{2.657(7346) + 1.771(4842)}{1367.201}\right](1000) = 22\,273 \text{ kPa}$$

396-m spans, 792-m LP

$$S_L = \left[\frac{1.5(21\,590) + 9338 + 3.286(7948) + 3.057(5239)}{44\,941} + \frac{2.657(7948) + 1.771(5239)}{1367.201}\right](1000) = 24\,098 \text{ kPa}$$

427-m spans, 854-m LP

$$S_L = \left[\frac{1.5(23\,280) + 10\,069 + 3.286(8570) + 3.057(5649)}{44\,941} + \frac{2.657(8570) + 1.771(5649)}{1367.201}\right](1000) = 25\,984 \text{ kPa}$$

Poles (at point N):

$$S_N = \left[\frac{1.5V_c + V_g + 6.002H_c + 4.864H_g}{69\,401} + \left(\frac{5.493H_c + 3.662H_g}{2\,616\,579}\right)\left(\frac{1000 \text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2 \text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

183-m spans, 366-m LP

$$S_N = \left[\frac{1.5(9977) + 4315 + 6.002(3673) + 4.864(2421)}{69\,401} + \frac{5.493(3673) + 3.662(2421)}{2616.579}\right](1000) = 11\,864 \text{ kPa}$$

213-m spans, 426-m LP

$$S_N = \left[\frac{1.5(11\,613) + 5023 + 6.002(4275) + 4.864(2818)}{69\,401} + \frac{5.493(4275) + 3.662(2818)}{2616.579}\right](1000) = 13\,809 \text{ kPa}$$

244-m spans, 488-m LP

$$S_N = \left[\frac{1.5(13\,303) + 5754 + 6.002(4897) + 4.864(3228)}{69\,401} + \frac{5.493(4897) + 3.662(3228)}{2616.579}\right](1000) = 15\,818\ \text{kPa}$$

274-m spans, 548-m LP

$$S_N = \left[\frac{1.5(14\,938) + 6461 + 6.002(5499) + 4.864(3625)}{69\,401} + \frac{5.493(5499) + 3.662(3625)}{2616.579}\right](1000) = 17\,763\ \text{kPa}$$

305-m spans, 610-m LP

$$S_N = \left[\frac{1.5(16\,629) + 7192 + 6.002(6121) + 4.864(4035)}{69\,401} + \frac{5.493(6121) + 3.662(4035)}{2616.579}\right](1000) = 19\,772\ \text{kPa}$$

335-m spans, 670-m LP

$$S_N = \left[\frac{1.5(18\,264) + 7899 + 6.002(6723) + 4.864(4432)}{69\,401} + \frac{5.493(6723) + 3.662(4432)}{2616.579}\right](1000) = 21\,716\ \text{kPa}$$

366-m spans, 732-m LP

$$S_N = \left[\frac{1.5(19\,954) + 8630 + 6.002(7346) + 4.864(4842)}{69\,401} + \frac{5.493(7346) + 3.662(4842)}{2616.579}\right](1000) = 23\,728\ \text{kPa}$$

396-m spans, 792-m LP

$$S_N = \left[\frac{1.5(21\,590) + 9338 + 6.002(7948) + 4.864(5239)}{69\,401} + \frac{5.493(7948) + 3.662(5239)}{2616.579}\right](1000) = 25\,673\ \text{kPa}$$

427-m spans, 854-m LP

$$S_N = \left[\frac{1.5(23\,280) + 10\,069 + 6.002(8570) + 4.864(5649)}{69\,401} + \frac{5.493(8570) + 3.662(5649)}{2616.579}\right](1000) = 27\,682\ \text{kPa}$$

Table 24 shows a summary of loads in the structure members for various span lengths and low point distances.

Table 24.–*Summary of loads in structure members for various span lengths and low-point distances (metric example 2)*

Member	Position	SAS/2, m								
		183	213	244	274	305	335	366	396	427
		LP, m								
		366	426	488	548	610	670	732	792	854
Adjustable braces, N	AG & EF	17 148	19 960	22 865	25 676	28 581	31 392	34 297	37 109	40 014
Nonadjustable braces, N	GC & FC	15 685	18 257	20 914	23 485	26 143	28 713	31 371	33 943	36 599
Crosstie, N	GF	6 455	7 514	8 607	9 665	10 759	11 817	12 910	13 969	15 062
Crossarm (compressive), N	AB & DE	17 245	20 072	22 993	25 820	28 742	31 568	34 489	37 317	40 238
Crossarm (compressive), N	BC & CD	20 695	24 088	27 593	30 985	34 492	37 884	41 389	44 782	48 287
X-brace, N	KN & LM	20 311	23 641	27 012	30 407	33 851	37 180	40 624	43 953	47 393
Pole, kPa	L	11 136	12 962	14 848	16 673	18 559	20 385	22 273	24 098	25 984
Pole, kPa	N	11 864	13 809	15 818	17 763	19 772	21 716	23 728	25 673	27 682

U.S. Customary

Figure 100 shows the structure outline and other data.

$$V_c = (1.8682)(\mathrm{LP}) \qquad V_g = (0.8079)(\mathrm{LP})$$

$$H_c = (1.3754)(\mathrm{SAS}/2) \qquad H_g = (0.9066)(\mathrm{SAS}/2)$$

Load in adjustable braces *AG* and *EF*:

$$L_{AG}' = L_{EF}' = V_c/\sin a = 1.635 V_c$$

Compression load in crossarm:

$$L_{AB}' = L_{DE}' = -V_c/\tan a = -1.294 V_c$$

Load in nonadjustable braces *GC* and *FC*:

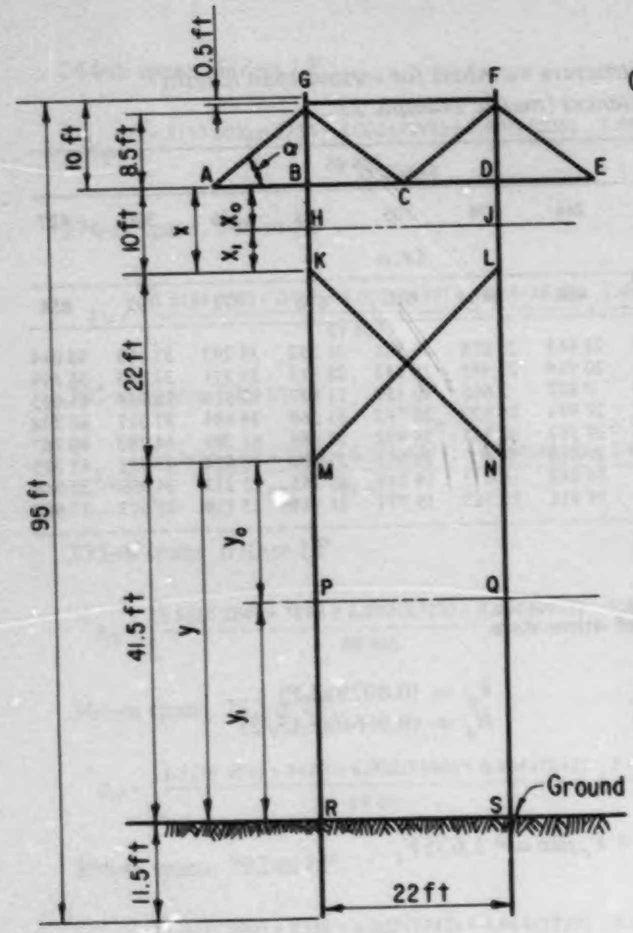
$$L_{GC}' = L_{FC}' = 0.5 V_c/\sin a = 0.818 V_c$$

Compressive force in crossarm between *B* and *C* and between *D* and *C*:

$$L_{BC}' = L_{DC}' = -V_c/\tan a = -1.294 V_c$$

Load in crosstie *GF*:

$$L_{GF}' = L_{AG}' \cos a - L_{GC}' \cos a = 0.647 V_c$$


0.5 ft
G
F
10 ft
8.5 ft
α
A
B
C
D
E
10 ft
x
X_0
X_1
H
J
K
L
22 ft
M
N
95 ft
y_0
P
Q
41.5 ft
y
y_1
R
S
Ground
11.5 ft
22 ft

Conductor: 795 kcmil, ACSR 45/7
Diameter = 1.063 in
8-lb/ft² wind on iced ($\frac{1}{2}$-in radial) conductor = 1.3754 lb/ft
Vertical force with $\frac{1}{2}$-in radial ice = 1.8682 lb/ft

OGW: $\frac{3}{8}$-in, H.S. Steel, 7-wire
Diameter = 0.360 in
8-lb/ft² wind on iced ($\frac{1}{2}$-in radial) OGW = 0.9066 lb/ft
Vertical force with $\frac{1}{2}$-in radial ice = 0.8079 lb/ft

Position	Pole Circumference, in	P_r, lb·ft
B or D	28.26	44 100
K or L	31.52	61 059
M or N	38.69	113 244
R or S	52.19	277 731

Douglas Fir
Working stress = 7400 lb/in²

$$\tan\alpha = \frac{8.5}{11} = 0.7727$$
$$\sin\alpha = 0.6114$$
$$\cos\alpha = 0.7913$$
$$\alpha = 37^\circ 41'$$

Figure 100.–95-ft type HSB 230-kV structure with class 2 Douglas fir poles (one X-brace). 104-D-1110.

Vertical loads, $3V_c$ and $2V_g$, are shared equally by two poles:

$$U_H' = U_J' = U_K' = U_L' = U_M' = U_N' = U_P' = U_Q' = U_R' = U_S' = 1.5V_c + V_g$$

For transverse loads H_c and H_g, a plane of inflection *HJ* exists. The location of this plane is found by:

$$x_0 = \frac{x(P_{rB})}{P_{rK} + P_{rB}} = \frac{10\,(44\,100)}{61\,059 + 44\,100} = 4.19 \text{ ft}$$

$$x_1 = x - x_0 = 10 - 4.19 = 5.81 \text{ ft}$$

A plane of inflection *PQ* also exists. Its location is found by:

$$y_0 = \frac{y(P_{rM})}{P_{rR} + P_{rM}} = \frac{41.5\,(113\,244)}{277\,731 + 113\,244} = 12.02 \text{ ft}$$

$$y_1 = y - y_0 = 41.5 - 12.02 = 29.48 \text{ ft}$$

When position of zero moment is known, the structure may be separated into parts and each part considered separately.

Horizontal wind forces on conductors and overhead ground wires are resisted equally by each pole at the points of zero moment.

$$R_H'' = R_J'' = R_P'' = R_Q'' = -\,1.5H_c - H_g$$

Axial reaction at *J* caused by horizontal wind force is found by taking moments about *H* and dividing by the moment arm (pole spacing).

$$U_J'' = \frac{(3H_c)\,(4.19) + 2H_g\,(13.69)}{22} = 0.571H_c + 1.244H_g$$

$$U_J'' = -\,U_H''$$

Taking moments about *B* in the pole above the plane of inflection (fig. 101), gives the force F_G'':

$$F_G'' = -\left[\frac{4.19\,(1.5H_c + H_g) + 9.5H_g}{8.5}\right] = -0.739H_c - 1.611H_g$$

$$F_F'' = F_G''$$

The outside braces, *AG* and *EF*, carry 10 percent of F_G'' and F_H'' while the inside braces, *CG* and *CF*, carry 90 percent. Load on the inner braces *CG* and *CF* is:

$$L_{CG}'' = \frac{0.9F_G''}{\cos a} = \frac{0.9\,(-0.739H_c - 1.611H_g)}{0.7913} = -\,0.841H_c - 1.832H_g$$

$$L_{CF}'' = -\,L_{CG}''$$

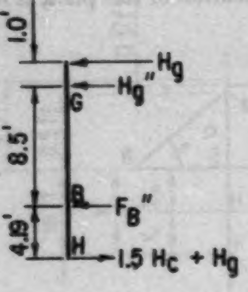


Figure 101.–Free body diagram of pole above plane of inflection and to the crosstie (U.S. customary example 2).

The load in the outer braces *AG* and *EF* is:

$$L_{AG}'' = \frac{-0.1(F_G'')}{\cos a} = \frac{-0.1(-0.739H_c - 1.611H_g)}{0.7913} = 0.0934H_c + 0.2036H_g$$

$$L_{EF}'' = -\,L_{AG}''$$

The load in the crossarm portions *BC* and *CD* is:

$$L_{BC}'' = (-L_{CG}'')\cos a + 0.5H_c = -\,(-0.841H_c - 1.832H_g)\,(0.7913) + 0.5H_c$$

$$= 1.165H_c + 1.448H_g$$

$$L_{BC}'' = -\,L_{CD}''$$

The load in the crossarm portions *AB* and *DE* is:

$$L_{AB}'' = -\,(L_{AG}''\cos a + H_c) = -\,(0.0934H_c + 0.204H_g)\,(0.7913) - H_c$$

$$= -1.074H_c - 0.161H_g$$

$$L_{AB}'' = -\,L_{DE}''$$

The moment at *B* and *D* is given by:

$$M_D'' = -\,x_0\,(1.5H_c + H_g) = -6.285H_c - 4.19H_g \text{ lb·ft}$$

$$M_B'' = M_D''$$

For the portion of pole between the planes of inflection, the moment at *K* and *L* is:

$$M_K'' = x_1\,(1.5H_c + H_g) = 5.81\,(1.5H_c + H_g) = 8.715H_c + 5.81H_g \text{ lb·ft}$$

$$M_L'' = M_K''$$

The area of the pole at *K* and *L*, excluding the 15/16-inch-diameter hole for mounting the X-brace is:

$$A_K = \frac{\pi D^2}{4} - \frac{15}{16}D = \frac{\pi}{4}(10.03)^2 - \frac{15}{16}(10.03) = 79.06 - 9.40 = 69.66 \text{ in}^2$$

$$A_L = A_K$$

The section modulus at *K* and *L* is:

$$Z_K = \frac{\pi D^3}{32} - \frac{15D^2/16}{6} = \frac{\pi}{32}(10.03)^3 - 0.15625\,(10.03)^2 = 99.06 - 15.72 = 83.34 \text{ in}^3$$

$$Z_L = Z_K$$

The horizontal reaction in the poles at *P* and *Q* is:

$$R_P'' = R_Q'' = -1.5H_c - H_g$$

The axial reaction in the poles at *P* and *Q* is:

$$U_Q'' = \left(\frac{3H_c + 2H_g}{22}\right)(39.83) + 0.571H_c + 1.244H_g = 6.002H_c + 4.864H_g$$

$$U_P'' = -\,U_Q''$$

The force at *K* can be found by taking moments about point *M* (fig. 102):

$$F_K'' = -\left[\frac{27.81\,(1.5H_c + H_g) + 12.02\,(1.5H_c + H_g)}{22}\right] = -2.715H_c - 1.813H_g$$

$$F_K'' = -\,F_M''$$

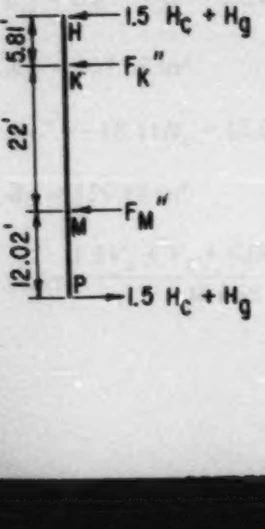


Figure 102.–Free body diagram of pole between planes of inflection (U.S. customary example 2).

The force in X-braces *KN* and *LM* is:

$$L_{KN}'' = -\left(\frac{2.715H_c + 1.813H_g}{\sin 45^\circ}\right) = -3.840H_c - 2.564H_g$$

$$L_{KN}'' = -\,L_{LM}''$$

The net area of the pole, less the X-brace mounting hole, at *M* and *N* is:

$$A_M = \frac{\pi D^2}{4} - \frac{15}{16}D = 119.12 - 11.54 = 107.58 \text{ in}^2$$

$$A_M = A_N$$

The section modulus at *M* and *N* is:

$$Z_M = \frac{\pi D^3}{32} - \frac{15D^2/16}{6} = 183.36 - 23.70 = 159.66 \text{ in}^3$$

$$Z_M = Z_N$$

Taking moments about point *M* (fig. 102):

$$M_M'' = -\,12.02\,(1.5H_c + H_g) = -\,18.11H_c - 12.02H_g$$

$$M_M'' = M_N''$$

By superposition, the values of the forces and bending moments computed separately for vertical and horizontal loading can be combined for total loading. The strength of each member can be divided by its respective total load and safety factors tabulated.

Stress in the poles is:

At point *L*:

$$S_L = \frac{P}{A} \pm \frac{M}{Z}$$

$$S_L = \frac{U_L}{A_L} \pm \frac{M_L}{Z_L}$$

where:

$U_L'' = U_J'' + 0.707L_{LM}''$ and $U_L = U_L' + U_L''$

$U_L'' = 0.571H_c + 1.244H_g + 0.707(3.840H_c + 2.564H_g) = 3.286H_c + 3.057H_g$

$U_L' = 1.5V_c + V_g$

$U_L = U_L' + U_L'' = 1.5V_c + V_g + 3.286H_c + 3.057H_g$

$A_L = 69.66\ \text{in}^2$

$M_L'' = 8.715H_c + 5.81H_g\ \text{lb}\cdot\text{ft}$

$Z_L = 83.34\ \text{in}^3$

$$S_L = \frac{1.5V_c + V_g + 3.286H_c + 3.057H_c}{69.66\ \text{in}^2} + \left(\frac{8.715H_c + 5.81H_g}{83.34\ \text{in}^3}\right)\left(\frac{12\ \text{in}}{\text{ft}}\right) = \text{lb/in}^2$$

At point N:

$$S_N = \frac{U_N}{A_N} \pm \frac{M_N}{Z_N}$$

where:

$U_N'' = U_Q''$ and $U_N = U_N' + U_N''$

$U_N' = 1.5V_c + V_g$

$U_N'' = 6.002H_c + 4.864H_g$

$U_N = U_N' + U_N'' = 1.5V_c + V_g + 6.002H_c + 4.864H_g$

$A_N = 107.58\ \text{in}^2$

$\mathrm{M}_N'' = -18.11H_c - 12.02H_g$

$Z_N = 159.66\ \text{in}^3$

$$S_N = \frac{1.5V_c + V_g + 6.002H_c + 4.864H_g}{107.58\ \text{in}^2} + \left(\frac{18.11H_c + 12.02H_g}{159.66\ \text{in}^3}\right)\left(\frac{12\ \text{in}}{\text{ft}}\right) = \text{lb/in}^2$$

Adjustable braces AG and EF:

	$L_{AG}' = 1.635V_c$	$L_{AG}'' = 0.0934H_c + 0.2036H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
600-ft Spans, LP = 1200 ft	3666	77.06 + 110.76 = 188	3854 lb
V_c = 2242 lb V_g = 970 lb H_c = 825 lb H_g = 544 lb			
700-ft Spans, LP = 1400 ft	4277	89.94 + 129.29 = 219	4496 lb
V_c = 2616 lb V_g = 1131 lb H_c = 963 lb H_g = 635 lb			
800-ft Spans, LP = 1600 ft	4887	102.74 + 147.61 = 250	5137 lb
V_c = 2989 lb V_g = 1293 lb H_c = 1100 lb H_g = 725 lb			
900-ft Spans, LP = 1800 ft	5499	115.63 + 166.14 = 282	5781 lb
V_c = 3363 lb V_g = 1454 lb H_c = 1238 lb H_g = 816 lb			
1000-ft Spans, LP = 2000 ft	6110	128.43 + 184.67 = 313	6423 lb
V_c = 3737 lb V_g = 1616 lb H_c = 1375 lb H_g = 907 lb			
1100-ft Spans, LP = 2200 ft	6720	141.31 + 202.99 = 344	7064 lb
V_c = 4110 lb V_g = 1777 lb H_c = 1513 lb H_g = 997 lb			
1200-ft Spans, LP = 2400 ft	7331	154.11 + 221.52 = 376	7707 lb
V_c = 4484 lb V_g = 1939 lb H_c = 1650 lb H_g = 1088 lb			
1300-ft Spans, LP = 2600 ft	7941	167.00 + 240.04 = 407	8348 lb
V_c = 4857 lb V_g = 2101 lb H_c = 1788 lb H_g = 1179 lb			
1400-ft Spans, LP = 2800 ft	8553	179.89 + 258.37 = 438	8991 lb
V_c = 5231 lb V_g = 2262 lb H_c = 1926 lb H_g = 1269 lb			

Nonadjustable braces *GC* and *FC*:

Spans, ft	LP, ft	$L_{GC}' = 0.818V_c$, lb	$L_{GC}'' = 0.841H_c + 1.832H_g$, lb	$L_{GC} = L_{GC}' + L_{GC}''$, lb
600	1200	1834	694 + 996 = 1690	3524
700	1400	2140	810 + 1163 = 1973	4113
800	1600	2445	925 + 1328 = 2253	4698
900	1800	2751	1041 + 1495 = 2536	5287
1000	2000	3057	1156 + 1661 = 2817	5874
1100	2200	3362	1272 + 1826 = 3098	6460
1200	2400	3668	1388 + 1993 = 3381	7049
1300	2600	3973	1504 + 2160 = 3664	7637
1400	2800	4279	1620 + 2324 = 3944	8223

Crosstie *GF*:

Spans, ft	LP, ft	$L_{GF}' = 0.647V_c$, lb
600	1200	1451
700	1400	1693
800	1600	1934
900	1800	2176
1000	2000	2418
1100	2200	2659
1200	2400	2901
1300	2600	3142
1400	2800	3384

Crossarm *AB* and *DE* (compressive):

Spans, ft	LP, ft	$L_{AB}' = -1.294V_c$, lb	$L_{AB}'' = -1.074H_c - 0.161H_g$, lb	$L_{AB} = L_{AB}' + L_{AB}''$, lb
600	1200	−2901	−886 − 88 = −974	−3875
700	1400	−3385	−1034 − 102 = −1136	−4521
800	1600	−3868	−1181 − 117 = −1298	−5166
900	1800	−4352	−1330 − 131 = −1461	−5813
1000	2000	−4836	−1477 − 146 = −1623	−6459
1100	2200	−5318	−1625 − 161 = −1786	−7104
1200	2400	−5802	−1772 − 175 = −1947	−7749
1300	2600	−6285	−1920 − 190 = −2110	−8395
1400	2800	−6769	−2069 − 204 = −2273	−9042

Crossarm *BC* and *CD* (compressive):

Spans, ft	LP, ft	$L_{CD}' = -1.294V_c$, lb	$L_{CD}'' = -1.165H_c - 1.448H_g$, lb	$L_{CD} = L_{CD}' + L_{CD}''$, lb
600	1200	−2901	−961 − 788 = −1749	−4 650
700	1400	−3385	−1122 − 919 = −2041	−5 426
800	1600	−3868	−1282 − 1050 = −2332	−6 200
900	1800	−4352	−1442 − 1182 = −2624	−6 976
1000	2000	−4836	−1602 − 1313 = −2915	−7 751
1100	2200	−5318	−1763 − 1444 = −3207	−8 525
1200	2400	−5802	−1922 − 1575 = −3497	−9 299
1300	2600	−6285	−2083 − 1707 = −3790	−10 075
1400	2800	−6769	−2244 − 1838 = −4082	−10 851

X-braces *KN* and *LM*:

Spans, ft	LP, ft	$L_{KN}'' = -3.840H_c - 2.564H_g$, lb
600	1200	−3168 − 1395 = −4 563
700	1400	−3698 − 1628 = −5 326
800	1600	−4224 − 1859 = −6 083
900	1800	−4754 − 2092 = −6 846
1000	2000	−5280 − 2326 = −7 606
1100	2200	−5810 − 2556 = −8 366
1200	2400	−6336 − 2790 = −9 126
1300	2600	−6866 − 3023 = −9 889
1400	2800	−7396 − 3254 = −10 650

Poles (at point *D*):

$$S_L = \frac{1.5V_c + V_g + 3.286H_c + 3.057H_g}{69.66} + \left(\frac{8.715H_c + 5.81H_g}{83.34}\right)\left(\frac{12}{1}\right) = \text{lb/in}^2$$

600-ft spans, 1200-ft LP

$$S_L = \frac{1.5(2242) + 970 + 3.286(825) + 3.057(544)}{69.66} + \left(\frac{8.715(825) + 5.81(544)}{83.34}\right)\left(\frac{12}{1}\right) = 1615\ \text{lb/in}^2$$

700-ft spans, 1400-ft LP

$$S_L = \frac{1.5(2616) + 1131 + 3.286(963) + 3.057(635)}{69.66} + \left(\frac{8.715(963) + 5.81(635)}{83.34}\right)\left(\frac{12}{1}\right) = 1886\ \text{lb/in}^2$$

800-ft spans, 1600-ft LP

$$S_L = \frac{1.5(2989) + 1293 + 3.286(1100) + 3.057(725)}{69.66} + \left(\frac{8.715(1100) + 5.81(725)}{83.34}\right)\left(\frac{12}{1}\right) = 2154\ \text{lb/in}^2$$

900-ft spans, 1800-ft LP

$$S_L = \frac{1.5(3363) + 1454 + 3.286(1238) + 3.057(816)}{69.66} + \left(\frac{8.715(1238) + 5.81(816)}{83.34}\right)\left(\frac{12}{1}\right) = 2424\ \text{lb/in}^2$$

1000-ft spans, 2000-ft LP

$$S_L = \frac{1.5(3737) + 1616 + 3.286(1375) + 3.057(907)}{69.66} + \left(\frac{8.715(1375) + 5.81(907)}{83.34}\right)\left(\frac{12}{1}\right) = 2693\ \text{lb/in}^2$$

1100-ft spans, 2200-ft LP

$$S_L = \frac{1.5(4110) + 1777 + 3.286(1513) + 3.057(997)}{69.66} + \left(\frac{8.715(1513) + 5.81(997)}{83.34}\right)\left(\frac{12}{1}\right) = 2961\ \text{lb/in}^2$$

1200-ft spans, 2400-ft LP

$$S_L = \frac{1.5(4484) + 1939 + 3.286(1650) + 3.057(1088)}{69.66} + \left(\frac{8.715(1650) + 5.81(1088)}{83.34}\right)\left(\frac{12}{1}\right) = 3231\ \text{lb/in}^2$$

1300-ft spans, 2600-ft LP

$$S_L = \frac{1.5(4857) + 2101 + 3.286(1788) + 3.057(1179)}{69.66} + \left(\frac{8.715(1788) + 5.81(1179)}{83.34}\right)\left(\frac{12}{1}\right) = 3501\ \text{lb/in}^2$$

1400-ft spans, 2800-ft LP

$$S_L = \frac{1.5(5231) + 2262 + 3.286(1926) + 3.057(1269)}{69.66} + \left(\frac{8.715(1926) + 5.81(1269)}{83.34}\right)\left(\frac{12}{1}\right) = 3770\ \text{lb/in}^2$$

Poles (at point N):

$$S_N = \frac{1.5V_c + V_g + 6.002H_c + 4.865H_g}{107.58} + \left(\frac{18.11H_c + 12.02H_g}{159.66}\right)\left(\frac{12}{1}\right) = \text{lb/in}^2$$

600-ft spans, 1200-ft LP

$$S_N = \frac{1.5(2242) + 970 + 6.002(825) + 4.865(544)}{107.58} + \left(\frac{18.11(825) + 12.02(544)}{159.66}\right)\left(\frac{12}{1}\right) = 1725\ \text{lb/in}^2$$

700-ft spans, 1400-ft LP

$$S_N = \frac{1.5(2616) + 1131 + 6.002(963) + 4.865(635)}{107.58} + \left(\frac{18.11(963) + 12.02(635)}{159.66}\right)\left(\frac{12}{1}\right) = 2013\ \text{lb/in}^2$$

800-ft spans, 1600-ft LP

$$S_N = \frac{1.5(2989) + 1293 + 6.002(1100) + 4.865(725)}{107.58} + \left(\frac{18.11(1100) + 12.02(725)}{159.66}\right)\left(\frac{12}{1}\right) = 2300\ \text{lb/in}^2$$

900-ft spans, 1800-ft LP

$$S_N = \frac{1.5(3363) + 1454 + 6.002(1238) + 4.865(816)}{107.58} + \left(\frac{18.11(1238) + 12.02(816)}{159.66}\right)\left(\frac{12}{1}\right) = 2589\ \text{lb/in}^2$$

1000-ft spans, 2000-ft LP

$$S_N = \frac{1.5(3737) + 1616 + 6.002(1375) + 4.865(907)}{107.58} + \left(\frac{18.11(1375) + 12.02(907)}{159.66}\right)\left(\frac{12}{1}\right) = 2876\ \text{lb/in}^2$$

1100-ft spans, 2200-ft LP

$$S_N = \frac{1.5(4110) + 1777 + 6.002(1513) + 4.865(997)}{107.58} + \left(\frac{18.11(1513) + 12.02(997)}{159.66}\right)\left(\frac{12}{1}\right) = 3163\ \text{lb/in}^2$$

1200-ft spans, 2400-ft LP

$$S_N = \frac{1.5(4484) + 1939 + 6.002(1650) + 4.865(1088)}{107.58} + \left(\frac{18.11(1650) + 12.02(1088)}{159.66}\right)\left(\frac{12}{1}\right) = 3451\ \text{lb/in}^2$$

1300-ft spans, 2600-ft LP

$$S_N = \frac{1.5(4857) + 2101 + 6.002(1788) + 4.865(1179)}{107.58} + \left(\frac{18.11(1788) + 12.02(1179)}{159.66}\right)\left(\frac{12}{1}\right) = 3739\ \text{lb/in}^2$$

1400-ft spans, 2800-ft LP

$$S_N = \frac{1.5(5231) + 2262 + 6.002(1926) + 4.865(1269)}{107.58} + \left(\frac{18.11(1926) + 12.02(1269)}{159.66}\right)\left(\frac{12}{1}\right) = 4027\ \text{lb/in}^2$$

Table 25 shows a summary of loads in the structure members for various span lengths and low point distances.

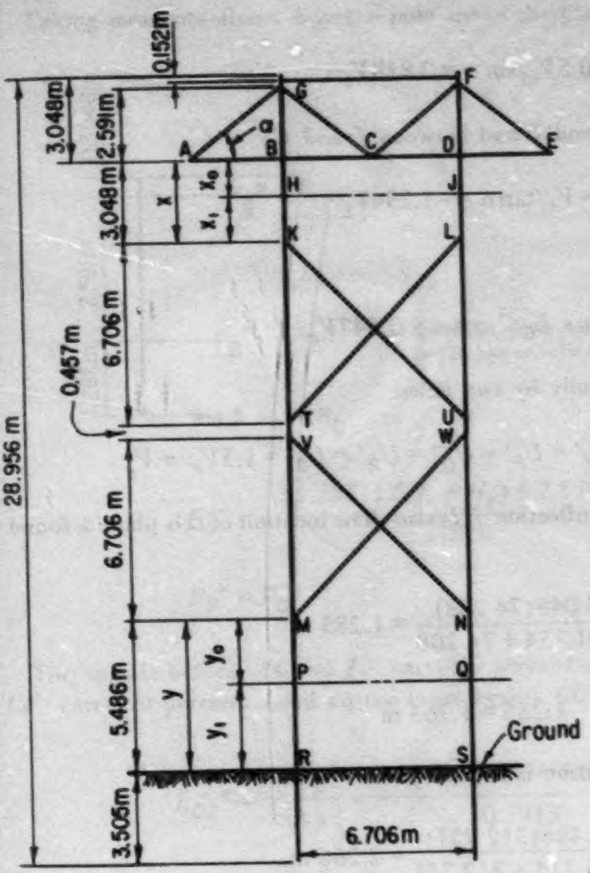
Table 25.–*Summary of loads in structure members for various spans lengths and low-point distances (U.S. customary example 2)*

Member	Position	SAS/2, ft								
		600	700	800	900	1 000	1 100	1 200	1 300	1 400
		LP, ft								
		1 200	1 400	1 500	1 800	2 000	2 200	2 400	2 600	2 800
Adjustable braces, lb	AG & EF	3 854	4 496	5 137	5 781	6 423	7 064	7 707	8 348	8 991
Nonadjustable braces, lb	GC & FC	3 524	4 113	4 698	5 287	5 874	6 460	7 049	7 637	8 223
Crosstie, lb	GF	1 451	1 693	1 934	2 176	2 418	2 659	2 901	3 142	3 384
Crossarm (compressive), lb	AB & DE	3 875	4 521	5 166	5 813	6 459	7 104	7 749	8 395	9 042
Crossarm (compressive), lb	BC & CD	4 650	5 426	6 200	6 976	7 751	8 525	9 299	10 075	10 851
X-brace, lb	KN & LM	4 563	5 326	6 083	6 846	7 606	8 366	9 126	9 889	10 650
Pole, lb/in^2	L	1 615	1 886	2 154	2 424	2 693	2 961	3 231	3 501	3 770
Pole, lb/in^2	N	1 725	2 013	2 300	2 589	2 876	3 163	3 451	3 739	4 027

Example 3.–Stress analysis for a 29-m (95-ft) type HSB 230-kV structure with class 1 wood poles and double X-brace:

Metric

Figure 103 shows the structure outline and other data. Using the nomenclature from example 1,


0.152m
3.048m
2.591m
3.048m
6.706 m
0.457m
6.706 m
5.486m
3.505m
28.956 m
6.706m
A
B
C
D
E
F
G
H
J
K
L
T
U
V
W
M
N
P
Q
R
S
a
x
x_0
x_1
y
y_0
y_1
Ground

Conductor: 403 mm², ACSR, 45/7
Diameter: 27 mm
0.38-kPa wind on iced (13-mm radial) conductor = 20.07 N/m
Vertical force with 13-mm radial ice = 27.26 N/m

OGW: 10 mm, H.S. Steel, 7-wire
Diameter = 9 mm
0.38-kPa wind on iced (13-mm radial) OGW = 13.23 N/m
Vertical force with 13-mm radial ice = 11.79 N/m

Position	Pole Circumference, mm	P_r, N·m
B or D	771	74 208
K or L	857	101 754
M or N	1247	312 751
R or S	1401	444 314

Douglas Fir
Working Stress = 51.02 MPa

$$\tan \alpha = \frac{2.591}{3.353} = 0.7727$$

$$\sin \alpha = 0.6114$$

$$\cos \alpha = 0.7913$$

$$\alpha = 37°41'$$

Figure 103.–29-m type HSB 230-kV structure with class 1 Douglas fir poles (two X-braces). 104-D-1111.

$$V_c = (27.26)(\mathrm{LP}) \qquad V_g = (11.79)(\mathrm{LP})$$

$$H_c = (20.07)(\mathrm{SAS}/2) \qquad H_g = (13.23)(\mathrm{SAS}/2)$$

Load in adjustable braces *AG* **and** *EF*:

$$L_{AG}' = L_{EF}' = V_c/\sin \alpha = 1.635V_c$$

Compression load in crossarm:

$$L_{AB}' = L_{DE}' = -V_c/\tan \alpha = -1.294V_c$$

Load in nonadjustable braces *GC* and *FC*:

$$L_{GC}' = L_{FC}' = 0.5V_c/\sin a = 0.818V_c$$

Compressive force in crossarm between *B* and *C* and between *D* and *C*:

$$L_{BC}' = L_{DC}' = -V_c/\tan a = -1.294V_c$$

Load in crosstie *GF*:

$$L_{GF}' = L_{AG}' \cos a - L_{GC}' \cos a = 0.647V_c$$

Vertical loads $3V_c$ and $2V_g$ are shared equally by two poles:

$$U_H' = U_J' = U_K' = U_L' = U_M' = U_N' = U_P' = U_Q' = U_R' = U_S' = 1.5V_c + V_g$$

For transverse loads H_c and H_g, a plane of inflection *HJ* exists. The location of this plane is found by:

$$x_0 = \frac{x(P_{rB})}{P_{rK} + P_{rB}} = \frac{3.048(74\ 208)}{101\ 754 + 74\ 208} = 1.285 \text{ m}$$

$$x_1 = x - x_0 = 3.048 - 1.285 = 1.763 \text{ m}$$

A plane of inflection *PQ* also exists. Its location is found by:

$$y_0 = \frac{y(P_{rM})}{P_{rR} + P_{rM}} = \frac{5.486(312\ 751)}{444\ 314 + 312\ 751} = 2.266 \text{ m}$$

$$y_1 = y - y_0 = 5.486 - 2.266 = 3.220 \text{ m}$$

When position of zero moment is known, the structure may be separated into parts and each part considered separately.

Horizontal wind forces on conductors and overhead ground wires are resisted equally by each pole at the points of zero moment:

$$R_H'' = R_J'' = R_P'' = R_Q'' = -1.5H_c - H_g$$

Axial reaction at *J* caused by horizontal wind force is found by taking moments about *H* and dividing by the moment arm (pole spacing):

$$U_J'' = \frac{(3H_c)(1.285) + (2H_g)(4.181)}{6.706} = 0.575H_c + 1.247H_g$$

$$U_J'' = -U_H''$$

Taking moments about B in the pole above the plane of inflection (fig. 104) gives force F_G'':

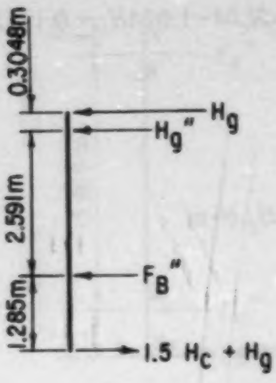


Figure 104.–Free body diagram of pole above plane of inflection and to the crosstie (metric example 3).

$$F_G'' = -\left[\frac{1.285(1.5H_c + H_g) + 2.896H_g}{2.591}\right] = -0.744H_c - 1.614H_g$$

$$F_F'' = F_G''$$

The outside braces, AG and EF, carry 10 percent of F_G'' and F_H'' while the inside braces, CG and CF, carry 90 percent. Load on the inner braces CG and CF is:

$$L_{CG}'' = \frac{0.9F_G''}{\cos a} = \frac{0.9(-0.744H_c - 1.614H_g)}{0.7913} = -0.846H_c - 1.836H_g$$

$$L_{CF}'' = -L_{CG}''$$

The load in the outer braces AG and EF is:

$$L_{AG}'' = \frac{-0.1F_G''}{\cos a} = \frac{-0.1(-0.744H_c - 1.614H_g)}{0.7913} = 0.0940H_c + 0.204H_g$$

$$L_{EF}'' = -L_{AG}''$$

The load in the crossarm portions BC and CD is:

$$L_{BC}'' = (-L_{CG}'')\cos a + 0.5H_c = -(-0.846H_c - 1.836H_g)(0.7913) + 0.5H_c$$

$$= 1.169H_c + 1.453H_g$$

$$L_{BC}'' = -L_{CD}''$$

The load in the crossarm portions *AB* and *DE* is:

$$L_{AB}'' = -(L_{AG}'' \cos a + H_c) = -(0.094H_c + 0.204H_g)(0.7913) - H_c = -1.074H_c - 0.161H_g$$

$$L_{AB}'' = -L_{DE}''$$

The moment at *B* and *D* is given by:

$$M_D'' = -x_0(1.5H_c + H_g) = -1.928H_c - 1.285H_g \text{ N·m}$$

$$M_B'' = M_D''$$

For the portion of pole between the planes of inflection, the moment at *K* and *L* is:

$$M_K'' = x_1(1.5H_c + H_g) = 2.645H_c + 1.763H_g \text{ N·m}$$

$$M_L'' = M_K''$$

The area of the pole at *K* and *L*, excluding the 23.8-mm-diameter hole for mounting the X-brace is:

$$A_K = \frac{\pi D^2}{4} - 23.8D = \frac{\pi}{4}(272.8)^2 - 23.8(272.8) = 58\,449 - 6493 = 51\,956 \text{ mm}^2$$

$$A_L = A_K$$

The section modulus at *K* and *L* is:

$$Z_K = \frac{\pi D^3}{32} - \frac{23.8D^2}{6} = \frac{\pi}{32}(272.8)^3 - \frac{23.8(272.8)^2}{6} = 1\,993\,118 - 295\,198 = 1\,697\,920 \text{ mm}^3$$

$$Z_L = Z_K$$

The horizontal reaction in the poles at *P* and *Q* is:

$$R_P'' = R_Q'' = -1.5H_c - H_g$$

The axial reaction in the poles at *P* and *Q* is:

$$U_Q'' = \frac{3H_c + 2H_g}{6.706}(17.898) + 0.575H_c + 1.247H_g = 8.581H_c + 6.585H_g$$

$$U_P'' = -U_Q''$$

The force at K can be found by taking moments about point M (fig. 105):

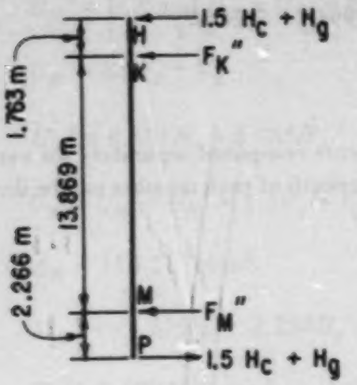


Figure 105.–Free body diagram of pole between planes of inflection (metric example 3).

$$F_K'' = -\left[\frac{15.632(1.5H_c + H_g) + 2.266(1.5H_c + H_g)}{6.706}\right] = -\ 4.003H_c - 2.669H_g$$

$$F_K'' = -F_M''$$

Since the division of load between X-braces KU and LT and X-braces VN and WM depends upon the installation, assume that all load is taken by one set of braces. The force in X-braces KU, LT, VN, and WM is:

$$L_{KU}'' = -\left(\frac{4.003H_c + 2.669H_g}{\sin 45^\circ}\right) = -5.662H_c - 3.775H_g$$

$$L_{KU}'' = -\ L_{LT}'' = L_{VN}'' = -L_{WM}''$$

The net area of the pole (less the X-brace mounting hole) at M and N is:

$$A_M = \frac{\pi D^2}{4} - 23.8D = \frac{\pi}{4}(396.80)^2 - 23.8(396.80) = 123\ 661 - 9444 = 114\ 217\ \text{mm}^2$$

$$A_M = A_N$$

The section modulus at M and N is:

$$Z_M = \frac{\pi D^3}{32} - \frac{23.8D^2}{6} = \frac{\pi}{32}(396.80)^3 - \frac{23.8}{6}(396.80)^2 = 6\ 133\ 592 - 624\ 553$$

$$= 5\ 509\ 039\ \text{mm}^3$$

$$Z_M = Z_N$$

Taking moments about point *M* (fig. 105):

$$M_M'' = -\ 2.266\,(1.5H_c + H_g) = -\ 3.399H_c - 2.266H_g$$

$$M_M'' = M_N''$$

By superposition, the values of the forces and bending moments computed separately for vertical and horizontal loading can be combined for total loading. The strength of each member can be divided by its respective total load and safety factors tabulated.

Stress in the poles is:

At point *L*:

$$S_L = \frac{P}{A} \pm \frac{M}{Z}$$

$$S_L = \frac{U_L}{A_L} \pm \frac{M_L}{Z_L}$$

where:

$U_L'' = U_J'' + 0.707L_{LT}''$ and $U_L = U_L' + U_L''$

$$U_L'' = 0.575H_c + 1.247H_g + 0.707(5.662H_c + 3.775H_g) = 4.578H_c + 3.916H_g$$

$$U_L' = 1.5V_c + V_g$$

$$U_L = U_L' + U_L'' = 1.5V_c + V_g + 4.578H_c + 3.916H_g$$

$$A_L = 51\ 956\ \text{mm}^2$$

$$M_L'' = 2.645H_c + 1.763H_g\ \text{N}\cdot\text{m}$$

$$Z_L = 1\ 697\ 920\ \text{mm}^3$$

$$S_L = \left[\frac{1.5V_c + V_g + 4.578H_c + 3.916H_g}{51\ 956\ \text{mm}^2} + \left(\frac{2.645H_c + 1.763H_g}{1\ 697\ 920\ \text{mm}^3}\right)\left(\frac{1000\ \text{mm}}{\text{m}}\right)\right]\left(\frac{1000^2\ \text{mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

At point *N*:

$$S_N = \frac{U_N}{A_N} \pm \frac{M_N}{Z_N}$$

where:

$$U_N'' = U_Q'' \text{ and } U_N = U_N' + U_N''$$

$$U_N' = 1.5V_c + V_g$$

$$U_N'' = 8.581H_c + 6.585H_g$$

$$U_N = U_N' + U_N'' = 1.5V_c + V_g + 8.581H_c + 6.585H_g$$

$$A_N = 114\,217 \text{ mm}^2$$

$$M_N'' = -3.399H_c - 2.266H_g$$

$$Z_N = 5\,509\,039 \text{ mm}^3$$

$$S_N = \left[\frac{1.5V_c + V_g + 8.581H_c + 6.585H_g}{114\,217 \text{ mm}^2} + \left(\frac{3.399H_c + 2.266H_g}{5\,509\,039 \text{ mm}^3}\right)\left(\frac{1000 \text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2 \text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

Adjustable braces *AG* and *EF*:

	$L_{AG}' = 1.635V_c$	$L_{AG}'' = 0.0940H_c + 0.204H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
183-m Spans, LP = 366 m V_c = 9977 N V_g = 4315 N H_c = 3673 N H_g = 2421 N	16 312	345.26 + 493.88 = 839	17 151 N
213-m Spans, LP = 426 m V_c = 11 613 N V_g = 5 023 N H_c = 4 275 N H_g = 2 818 N	18 987	401.85 + 574.87 = 977	19 964 N
244-m Spans, LP = 488 m V_c = 13 303 N V_g = 5 754 N H_c = 4 897 N H_g = 3 228 N	21 750	460.32 + 658.51 = 1119	22 869 N
274-m Spans, LP = 548 m V_c = 14 938 N V_g = 6 461 N H_c = 5 499 N H_g = 3 625 N	24 424	516.91 + 739.50 = 1256	25 680 N

Adjustable braces *AG* and *EF*–Continued

	$L_{AG}' = 1.635V_c$	$L_{AG}'' = 0.0940H_c + 0.204H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
305-m Spans, LP = 610 m V_c = 16 629 N V_g = 7 192 N H_c = 6 121 N H_g = 4 035 N	27 188	575.37 + 823.14 = 1399	28 587 N
335-m Spans, LP = 670 m V_c = 18 264 N V_g = 7 899 N H_c = 6 723 N H_g = 4 432 N	29 862	631.96 + 904.13 = 1536	31 398 N
366-m Spans, LP = 732 m V_c = 19 954 N V_g = 8 630 N H_c = 7 346 N H_g = 4 842 N	32 625	690.52 + 987.77 = 1678	34 303 N
396-m Spans, LP = 792 m V_c = 21 590 N V_g = 9 338 N H_c = 7 948 N H_g = 5 239 N	35 300	747.11 + 1068.76 = 1816	37 116 N
427-m Spans, LP = 854 m V_c = 23 280 N V_g = 10 069 N H_c = 8 570 N H_g = 5 649 N	38 063	805.58 + 1152.40 = 1958	40 021 N

Nonadjustable braces *GC* and *FC*:

Spans, m	LP, m	$L_{GC}' = 0.818V_c$, N	$L_{GC}'' = 0.846H_c + 1.836H_g$, N	$L_{GC} = L_{GC}' + L_{GC}''$, N
183	366	8 161	3107 + 4 445 = 7 552	15 713
213	426	9 499	3617 + 5 174 = 8 791	18 290
244	488	10 882	4128 + 5 927 = 10 055	20 937
274	548	12 219	4652 + 6 656 = 11 308	23 572
305	610	13 603	5178 + 7 408 = 12 586	26 189
335	670	14 940	5688 + 8 137 = 13 825	28 765
366	732	16 322	6215 + 8 890 = 15 105	31 427
396	792	17 661	6724 + 9 619 = 16 343	34 004
427	854	19 043	7250 + 10 372 = 17 622	36 665

Crosstie *GF*:

Spans, m	LP, m	$L_{GF}' = 0.647V_c$, N
183	366	6 455
213	426	7 514
244	488	8 607
274	548	9 665
305	610	10 759
335	670	11 817
366	732	12 910
396	792	13 969
427	854	15 062

Crossarm *AB* and *DE* (compressive):

Spans, m	LP, m	$L_{AB}' = -1.294V_c$, N	$L_{AB}'' = -1.074H_c - 0.161H_g$, N	$L_{AB} = L_{AB}' + L_{AB}''$, N
183	366	−12 910	−3945 − 390 = −4 335	−17 245
213	426	−15 027	−4591 − 454 = −5 045	−20 072
244	488	−17 214	−5259 − 520 = −5 779	−22 993
274	548	−19 330	−5906 − 584 = −6 490	−25 820
305	610	−21 518	−6574 − 650 = −7 224	−28 742
335	670	−23 634	−7221 − 714 = −7 935	−31 569
366	732	−25 820	−7890 − 780 = −8 670	−34 490
396	792	−27 937	−8536 − 843 = −9 379	−37 316
427	854	−30 124	−9204 − 909 = −10 113	−40 237

Crossarm *BC* and *CD* (compressive):

Spans, m	LP, m	$L_{CD}' = -1.294V_c$, N	$L_{CD}'' = -1.169H_c - 1.453H_g$, N	$L_{CD} = L_{CD}' + L_{CD}''$, N
183	366	−12 910	−4 294 − 3518 = −7 812	−20 722
213	426	−15 027	−4 997 − 4095 = −9 092	−24 119
244	488	−17 214	−5 725 − 4690 = −10 415	−27 629
274	548	−19 330	−6 428 − 5267 = −11 695	−31 025
305	610	−21 518	−7 155 − 5863 = −13 018	−34 536
335	670	−23 634	−7 859 − 6440 = −14 299	−37 933
366	732	−25 820	−8 587 − 7035 = −15 622	−41 442
396	792	−27 937	−9 291 − 7612 = −16 903	−44 840
427	854	−30 124	−10 018 − 8208 = −18 226	−48 350

X-brace:

Spans, m	LP, m	$L_{KU}'' = -5.662H_c - 3.775H_g$, N
183	366	−20 796 − 9 139 = −29 935
213	426	−24 205 − 10 638 = −34 843
244	488	−27 727 − 12 186 = −39 913
274	548	−31 135 − 13 684 = −44 819
305	610	−34 657 − 15 232 = −49 889
335	670	−38 066 − 16 731 = −54 797
366	732	−41 593 − 18 279 = −59 872
396	792	−45 002 − 19 777 = −64 779
427	854	−48 523 − 21 325 = −69 848

Poles (at point L):

$$S_L = \left[\frac{1.5V_c + V_g + 4.578H_c + 3.916H_g}{51\,956 \text{ mm}^2} + \left(\frac{2.645H_c + 1.763H_g}{1\,697\,920 \text{ mm}^3}\right)\left(\frac{1000 \text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2 \text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

183-m spans, 366-m LP

$$S_L = \left[\frac{1.5(9977) + 4315 + 4.578(3673) + 3.916(2421)}{51\,956} + \frac{2.645(3673) + 1.763(2421)}{1697.92}\right](1000) = 9113 \text{ kPa}$$

213-m spans, 426-m LP

$$S_L = \left[\frac{1.5(11\,613) + 5023 + 4.578(4275) + 3.916(2818)}{51\,956} + \frac{2.645(4275) + 1.763(2818)}{1697.92}\right](1000) = 10\,607 \text{ kPa}$$

244-m spans, 488-m LP

$$S_L = \left[\frac{1.5(13\,303) + 5754 + 4.578(4897) + 3.916(3228)}{51\,956} + \frac{2.645(4897) + 1.763(3228)}{1697.92}\right](1000) = 12\,150 \text{ kPa}$$

274-m spans, 548-m LP

$$S_L = \left[\frac{1.5(14\,938) + 6461 + 4.578(5499) + 3.916(3625)}{51\,956} + \frac{2.645(5499) + 1.763(3625)}{1697.92}\right](1000) = 13\,644 \text{ kPa}$$

305-m spans, 610-m LP

$$S_L = \left[\frac{1.5(16\,629) + 7192 + 4.578(6121) + 3.916(4035)}{51\,956} + \frac{2.645(6121) + 1.763(4035)}{1697.92}\right](1000) = 15\,187 \text{ kPa}$$

335-m spans, 670-m LP

$$S_L = \left[\frac{1.5(18\,264) + 7899 + 4.578(6723) + 3.916(4432)}{51\,956} + \frac{2.645(6723) + 1.763(4432)}{1697.92}\right](1000) = 16\,681 \text{ kPa}$$

366-m spans, 732-m LP

$$S_L = \left[\frac{1.5(19\,954) + 8630 + 4.578(7346) + 3.916(4842)}{51\,956} + \frac{2.645(7346) + 1.763(4842)}{1697.92}\right](1000) = 18\,225 \text{ kPa}$$

396-m spans, 792-m LP

$$S_L = \left[\frac{1.5(21\,590) + 9338 + 4.578(7948) + 3.916(5239)}{51\,956} + \frac{2.645(7948) + 1.763(5239)}{1697.92}\right](1000) = 19\,719 \text{ kPa}$$

427-m spans, 854-m LP

$$S_L = \left[\frac{1.5\,(23\ 280) + 10\ 069 + 4.578\,(8570) + 3.916\,(5649)}{51\ 956} + \frac{2.645\,(8570) + 1.763\,(5649)}{1697.92}\right](1000) = 21\ 262 \text{ kPa}$$

Poles (at point N):

$$S_N = \left[\frac{1.5V_c + V_g + 8.581H_c + 6.585H_g}{114\ 217 \text{ mm}^2} + \left(\frac{3.399H_c + 2.266H_g}{5\ 509\ 039 \text{ mm}^3}\right)\left(\frac{1000 \text{ mm}}{\text{m}}\right)\right]\left(\frac{1000^2 \text{ mm}^2}{\text{m}^2}\right) \div 1000 = \text{kPa}$$

183-m spans, 366-m LP

$$S_N = \left[\frac{1.5\,(9977) + 4315 + 8.581\,(3673) + 6.585\,(2421)}{114\ 217} + \frac{3.399\,(3673) + 2.266\,(2421)}{5509.039}\right](1000) = 3846 \text{ kPa}$$

213-m spans, 426-m LP

$$S_N = \left[\frac{1.5\,(11\ 613) + 5023 + 8.581\,(4275) + 6.585\,(2818)}{114\ 217} + \frac{3.399\,(4275) + 2.266\,(2818)}{5509.039}\right](1000) = 4477 \text{ kPa}$$

244-m spans, 488-m LP

$$S_N = \left[\frac{1.5\,(13\ 303) + 5754 + 8.581\,(4897) + 6.585\,(3228)}{114\ 217} + \frac{3.399\,(4897) + 2.266\,(3228)}{5509.039}\right](1000) = 5128 \text{ kPa}$$

274-m spans, 548-m LP

$$S_N = \left[\frac{1.5\,(14\ 938) + 6461 + 8.581\,(5499) + 6.585\,(3625)}{114\ 217} + \frac{3.399\,(5499) + 2.266\,(3625)}{5509.039}\right](1000) = 5759 \text{ kPa}$$

305-m spans, 610-m LP

$$S_N = \left[\frac{1.5\,(16\ 629) + 7192 + 8.581\,(6121) + 6.585\,(4035)}{114\ 217} + \frac{3.399\,(6121) + 2.266\,(4035)}{5509.039}\right](1000) = 6410 \text{ kPa}$$

335-m spans, 670-m LP

$$S_N = \left[\frac{1.5\,(18\ 264) + 7899 + 8.581\,(6723) + 6.585\,(4432)}{114\ 217} + \frac{3.399\,(6723) + 2.266\,(4432)}{5509.039}\right](1000) = 7040 \text{ kPa}$$

366-m spans, 732-m LP

$$S_N = \left[\frac{1.5\,(19\ 954) + 8630 + 8.581\,(7346) + 6.585\,(4842)}{114\ 217} + \frac{3.399\,(7346) + 2.266\,(4842)}{5509.039}\right](1000) = 7693 \text{ kPa}$$

396-m spans, 792-m LP

$$S_N = \left[\frac{1.5(21\,590) + 9338 + 8.581(7948) + 6.585(5239)}{114\,217} + \frac{3.399(7948) + 2.266(5239)}{5509.039}\right](1000) = 8323 \text{ kPa}$$

427-m spans, 854-m LP

$$S_N = \left[\frac{1.5(23\,280) + 10\,069 + 8.581(8570) + 6.585(5649)}{114\,217} + \frac{3.399(8570) + 2.266(5649)}{5509.039}\right](1000) = 8974 \text{ kPa}$$

Table 26 shows a summary of loads in the structure members for various span lengths and low point distances.

Table 26.–*Summary of loads in structure members for various span lengths and low-point distances (metric example 3)*

Member	Position	SAS/2, m								
		183	213	244	274	305	335	366	396	427
		LP, m								
		366	426	488	548	610	670	732	792	854
Adjustable braces, N	AG & EF	17 151	19 964	22 869	25 680	28 587	31 398	34 303	37 116	40 021
Nonadjustable braces, N	GC & FC	15 713	18 290	20 937	23 572	26 189	28 765	31 427	34 004	36 665
Crosstie, N	GF	6 455	7 514	8 607	9 665	10 759	11 817	12 910	13 969	15 062
Crossarm (compressive), N	AB & DE	17 245	20 072	22 993	25 820	28 742	31 569	34 490	37 316	40 237
Crossarm (compressive), N	BC & CD	20 722	24 119	27 629	31 025	34 536	37 933	41 442	44 840	48 350
X-brace, N	KN & LM	29 935	34 843	39 913	44 819	49 889	54 797	59 872	64 779	69 848
Pole, kPa	L	9 113	10 607	12 150	13 644	15 187	16 681	18 225	19 719	21 262
Pole, kPa	N	3 846	4 477	5 128	5 759	6 410	7 040	7 693	8 323	8 974

U.S. Customary

Figure 106 shows the structure outline and other data.

$$V_c = (1.8682)(\text{LP}) \qquad V_g = (0.8079)(\text{LP})$$
$$H_c = (1.3754)(\text{SAS}/2) \qquad H_g = (0.9066)(\text{SAS}/2)$$

Load in adjustable braces *AG* and *EF*:

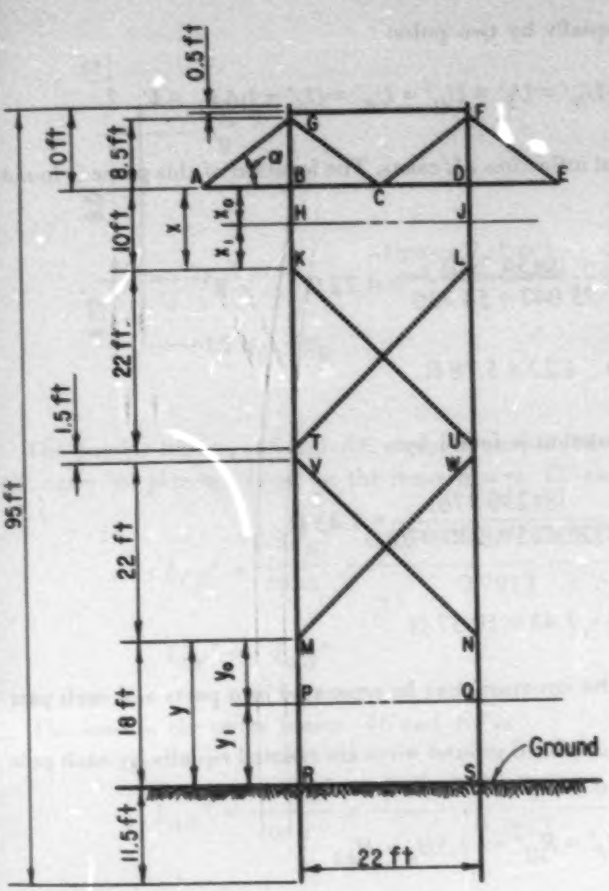
$$L_{AG}' = L_{EF}' = V_c/\sin\alpha = 1.635V_c$$

Compression load in crossarm:

$$L_{AB}' = L_{DE}' = -\ V_c/\tan\alpha = -1.294V_c$$

Load in nonadjustable braces *GC* and *FC*:

$$L_{GC}' = L_{FC}' = 0.5V_c/\sin\alpha = 0.818V_c$$


0.5 ft
10 ft
8.5 ft
α
A
G
B
C
D
F
E
H
J
K
L
X
X_0
X_1
10 ft
22 ft.
1.5 ft
T
U
V
W
95 ft
22 ft
M
N
Y_0
P
Q
18 ft
Y
Y_1
Ground
R
S
11.5 ft
22 ft

Conductor: 759 kcmil, ACSR, 45/7
Diameter = 1.063 in
8-lb/ft² wind on iced ($\frac{1}{2}$-in radial) conductor = 1.3754 lb/ft
Vertical force with $\frac{1}{2}$-in radial ice = 1.8682 lb/ft
OGW: $\frac{3}{8}$-in, H.S. steel, 7-wire
Diameter = 0.360 in
8-lb/ft² wind on iced ($\frac{1}{2}$-in radial) OGW = 0.9066 lb/ft
Vertical force with $\frac{1}{2}$-in radial ice = 0.8079 lb/ft

Position	Pole Circumference, in	P_r, lb·ft
B or D	30.37	54 730
K or L	33.74	75 047
M or N	49.08	230 976
R or S	55.15	328 655

Douglas Fir
Working stress = 7400 lb/in²

$\tan\alpha = \frac{8.5}{11} = 0.7727$
$\sin\alpha = 0.6114$
$\cos\alpha = 0.7913$
$\alpha = 37°41'$

Figure 106.–95-ft type HSB 230-kV structure with class 1 Douglas fir poles (two X-braces). 104-D-1112.

Compressive force in crossarm between *B* and *C* and between *D* and *C*:

$$L_{BC}' = L_{DC}' = -V_c/\tan\alpha = -1.294\,V_c$$

Load in crosstie *GF*:

$$L_{GF}' = L_{AG}'\cos\alpha - L_{GC}'\cos\alpha = 0.647\,V_c$$

Vertical loads $3V_c$ and $2V_g$ are shared equally by two poles:

$$U_H' = U_J' = U_K' = U_L' = U_M' = U_N' = U_P' = U_Q' = U_R' = U_S' = 1.5V_c + V_g$$

For transverse loads H_c and H_g, a plane of inflection HJ exists. The location of this plane is found by:

$$x_0 = \frac{x(P_{rB})}{P_{rK} + P_{rB}} = \frac{10(54\,730)}{75\,047 + 54\,730} = 4.22 \text{ ft}$$

$$x_1 = x - x_0 = 10 - 4.22 = 5.78 \text{ ft}$$

A plane of inflection PQ also exists. Its location is found by:

$$y_0 = \frac{y(P_{rM})}{P_{rR} + P_{rM}} = \frac{18(230\,976)}{328\,655 + 230\,976} = 7.43 \text{ ft}$$

$$y_1 = y - y_0 = 18.0 - 7.43 = 10.57 \text{ ft}$$

When position of zero moment is known, the structure may be separated into parts and each part considered separately.

Horizontal wind forces on conductors and overhead ground wires are resisted equally by each pole at the points of zero moment:

$$R_H'' = R_J'' = R_P'' = R_Q'' = -1.5H_c - H_g$$

Axial reaction at J caused by horizontal wind force is found by taking moments about H and dividing by the moment arm (pole spacing):

$$U_J'' = \frac{(3H_c)(4.22) + (2H_g)(13.77)}{22} = 0.575H_c + 1.252H_g$$

$$U_J'' = -U_H''$$

Taking moments about B in the pole above the plane of inflection (fig. 107) gives force F_G'':

$$F_G'' = -\left[\frac{4.22(1.5H_c + H_g) + 9.5H_g}{8.5}\right] = -0.745H_c - 1.614H_g$$

$$F_F'' = F_G''$$

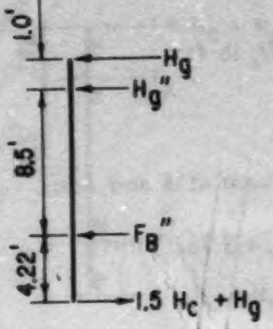


Figure 107.–Free body diagram of pole above plane of inflection and to the crosstie (U.S. customary example 3).

The outside braces, *AG* and *EF*, carry 10 percent of F_G'' and F_H'' while the inside braces, *CG* and *CF*, carry 90 percent. Load on the inner braces, *CG* and *CF*, is:

$$L_{CG}'' = \frac{0.9F_G''}{\cos a} = \frac{0.9\,(-0.745H_c - 1.614H_g)}{0.7913} = -0.847H_c - 1.836H_g$$

$$L_{CF}'' = -\,L_{CG}''$$

The load in the outer braces *AG* and *EF* is:

$$L_{AG}'' = \frac{-0.1F_G''}{\cos a} = \frac{-0.1\,(-0.745H_c - 1.614H_g)}{0.7913} = 0.0941H_c + 0.204H_g$$

$$L_{EF}'' = -\,L_{AG}''$$

The load in the crossarm portions *BC* and *CD* is:

$$L_{BC}'' = (-L_{CG}'')\cos a + 0.5H_c = -\,(-0.847H_c - 1.836H_g)\,(0.7913) + 0.5H_c$$

$$= 1.170H_c + 1.453H_g$$

$$L_{BC}'' = -\,L_{CD}''$$

The load in the crossarm portions *AB* and *DE* is:

$$L_{AB}'' = -\,(L_{AG}''\cos a + H_c) = -\,(0.0941H_c + 0.204H_g)\,(0.7913) - H_c$$

$$= -1.074H_c - 0.161H_g$$

$$L_{AB}'' = -\,L_{DE}''$$

The moment at B and D is given by:

$$M_D'' = -x_0(1.5H_c + H_g) = -6.33H_c - 4.22H_g \text{ lb}\cdot\text{ft}$$

$$M_B'' = M_D''$$

For the portion of pole between the planes of inflection, the moment at K and L is:

$$M_K'' = x_1(1.5H_c + H_g) = 5.78(1.5H_c + H_g) = 8.67H_c + 5.78H_g \text{ lb}\cdot\text{ft}$$

$$M_L'' = M_K''$$

The area of the pole at K and L, excluding the 15/16-inch-diameter hole for mounting the X-brace is:

$$A_K = \frac{\pi D^2}{4} - \frac{15}{16}D = \frac{\pi}{4}(10.74)^2 - \frac{15}{16}(10.74) = 90.59 - 10.07 = 80.52 \text{ in}^2$$

$$A_L = A_K$$

The section modulus at K and L is:

$$Z_K = \frac{\pi D^3}{32} - \frac{15D^2/16}{6} = \frac{\pi}{32}(10.74)^3 - 0.15625(10.74)^2 = 121.62 - 18.02 = 103.6 \text{ in}^3$$

$$Z_L = Z_K$$

The horizontal reaction in the poles at P and Q is:

$$R_P'' = R_Q'' = -1.5H_c - H_g$$

The axial reaction in the poles at P and Q is:

$$U_Q'' = \left(\frac{3H_c + 2H_g}{22}\right)(58.71) + 0.575H_c + 1.252H_g = 8.581H_c + 6.589H_g$$

$$U_P'' = -U_Q''$$

The force at K can be found by taking moments about point M (fig. 108):

$$F_K'' = -\left[\frac{51.28(1.5H_c + H_g) + 7.43(1.5H_c + H_g)}{22}\right] = -4.003H_c - 2.669H_g$$

$$F_K'' = -F_M''$$

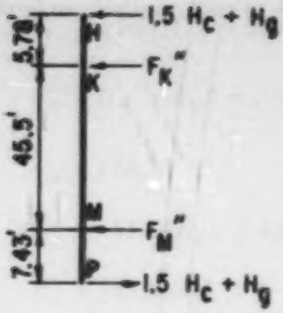


Figure 108.–Free body diagram of pole between planes of inflection (U.S. customary example 3).

Since the division of load between X-braces *KU* and *LT* and X-braces *VN* and *WM* depends upon installation, assume that all load is taken by one set of braces. The force in X-braces *KU*, *LT*, *VN*, and *WM* is:

$$L_{KU}'' = -\left(\frac{4.003H_c + 2.669H_g}{\sin 45^{\circ}}\right) = -5.662H_c - 3.775H_g$$

$$L_{KU}'' = -L_{LT}'' = L_{VN}'' = -L_{WM}''$$

The net area of the pole (less the X-brace mounting hole) at *M* and *N* is:

$$A_M = \frac{\pi D^2}{4} - \frac{15}{16}\text{D} = \frac{\pi}{4}(15.62)^2 - \frac{15}{16}(15.62) = 191.62 - 14.64 = 176.88 \text{ in}^2$$

$$A_M = A_N$$

The section modulus at *M* and *N* is:

$$Z_M = \frac{\pi D^3}{32} - \frac{15D^2/16}{6} = 0.098(15.62)^3 - 0.15625(15.62)^2 = 373.48 - 38.21 = 335.36 \text{ in}^3$$

$$Z_M = Z_N$$

Taking moments about point *M* (fig. 108):

$$M_M'' = -7.43(1.5H_c + H_g) = -11.14H_c - 7.43H_g$$

$$M_M'' = M_N''$$

By superposition, the values of the forces and bending moments computed separately for vertical and horizontal loading can be combined for total loading. The strength of each member can be divided by its respective total load and safety factors tabulated.

Stress in the poles is:

At point L:

$$S_L = \frac{P}{A} \pm \frac{M}{Z}$$

$$S_L = \frac{U_L}{A_L} \pm \frac{M_L}{Z_L}$$

where:

$U_L'' = U_J'' + 0.707 L_{LT}''$ and $U_L = U_L' + U_L''$

$U_L'' = 0.575 H_c + 1.252 H_g + 0.707\,(5.662 H_c + 3.775 H_g) = 4.578 H_c + 3.921 H_g$

$U_L' = 1.5 V_c + V_g$

$U_L = U_L' + U_L'' = 1.5 V_c + V_g + 4.578 H_c + 3.921 H_g$

$A_L = 80.52\ \text{in}^2$

$M_L'' = 8.67 H_c + 5.78 H_g\ \text{lb}\cdot\text{ft}$

$Z_L = 103.60\ \text{in}^3$

$$S_L = \frac{U_L' + U_L''}{A_L} + \left(\frac{M_L''}{Z_L}\right)\left(\frac{12\ \text{in}}{\text{ft}}\right)$$

$$= \frac{1.5 V_c + V_g + 4.578 H_c + 3.921 H_g}{80.52\ \text{in}^2} + \left(\frac{8.67 H_c + 5.78 H_g}{103.6\ \text{in}_3}\right)\left(\frac{12\ \text{in}}{\text{ft}}\right) = \text{lb/in}^2$$

Poles (at point N):

$$S_N = \frac{U_N}{A_N} \pm \frac{M_N}{Z_N}$$

where:

$U_N'' = U_Q''$ and $U_N = U_N' + U_N''$

$$U_N' = 1.5V_c + V_g$$

$$U_N'' = 8.581H_c + 6.589H_g$$

$$U_N = U_N' + U_N'' = 1.5V_c + V_g + 8.581H_c + 6.589H_g$$

$$A_N = 176.98 \text{ in}^2$$

$$M_N'' = -11.14H_c - 7.43H_g$$

$$Z_N = 335.36 \text{ in}^3$$

$$S_N = \frac{1.5V_c + V_g + 8.581H_c + 6.589H_g}{176.98 \text{ in}^2} + \left(\frac{11.14H_c + 7.43H_g}{335.36 \text{ in}^3}\right)\left(\frac{12 \text{ in}}{\text{ft}}\right) = \text{lb/in}^2$$

Adjustable braces *AG* and *EF*:

	$L_{AG}' = 1.635V_c$	$L_{AG}'' = 0.0940H_c + 0.204H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
600-ft Spans, LP = 1200 ft $V_c = 2242$ lb $V_g = 970$ lb $H_c = 825$ lb $H_g = 544$ lb	**3666**	**77.63 + 110.98 = 189**	**3855 lb**
700-ft Spans, LP = 1400 ft $V_c = 2616$ lb $V_g = 1131$ lb $H_c = 963$ lb $H_g = 635$ lb	**4277**	**90.62 + 129.54 = 220**	**4497 lb**
800-ft Spans, LP = 1600 ft $V_c = 2989$ lb $V_g = 1293$ lb $H_c = 1100$ lb $H_g = 725$ lb	**4887**	**103.51 + 147.90 = 251**	**5138 lb**
900-ft Spans, LP = 1800 ft $V_c = 3363$ lb $V_g = 1454$ lb $H_c = 1238$ lb $H_g = 816$ lb	**5499**	**116.50 + 166.46 = 283**	**5782 lb**
1000-ft Spans, LP = 2000 ft $V_c = 3737$ lb $V_g = 1616$ lb $H_c = 1375$ lb $H_g = 907$ lb	**6110**	**129.39 + 185.03 = 315**	**6425 lb**

Adjustable braces *AG* and *EF*—Continued

	$L_{AG}' = 1.635V_c$	$L_{AG}'' = 0.0940H_c + 0.204H_g$	$L_{AG} = L_{AG}' + L_{AG}''$
1100-ft Spans, LP = 2200 ft V_c = 4110 lb V_g = 1777 lb H_c = 1513 lb H_g = 997 lb	6720	142.37 + 203.39 = 346	7066 lb
1200-ft Spans, LP = 2400 ft V_c = 4484 lb V_g = 1939 lb H_c = 1650 lb H_g = 1088 lb	7331	155.27 + 221.95 = 377	7708 lb
1300-ft Spans, LP = 2600 ft V_c = 4857 lb V_g = 2101 lb H_c = 1788 lb H_g = 1179 lb	7924	168.25 + 240.43 = 409	8351 lb
1400-ft Spans, LP = 2800 ft V_c = 5231 lb V_g = 2262 lb H_c = 1926 lb H_g = 1269 lb	8553	181.20 + 258.92 = 440	8993 lb

Nonadjustable braces *GC* and *FC*:

Spans, ft	LP, ft	$L_{GC}' = 0.818V_c$, lb	$L_{GC}'' = 0.847H_c + 1.836H_g$, lb	$L_{GC} = L_{GC}' + L_{GC}''$, lb
600	1200	1834	699 + 999 = 1698	3532
700	1400	2140	816 + 1165 = 1981	4121
800	1600	2445	932 + 1332 = 2264	4709
900	1800	2751	1049 + 1498 = 2547	5298
1000	2000	3057	1165 + 1665 = 2830	5887
1100	2200	3362	1282 + 1831 = 3113	6475
1200	2400	3668	1398 + 1998 = 3396	7064
1300	2600	3973	1515 + 2164 = 3679	7652
1400	2800	4279	1631 + 2330 = 3961	8240

Crosstie *GF*:

Spans, ft	LP, ft	$L_{GF}' = 0.647V_c$, lb
600	1200	1451
700	1400	1693
800	1600	1934
900	1800	2176
1000	2000	2418
1100	2200	2659
1200	2400	2901
1300	2600	3142
1400	2800	3384

Crossarm *AB* and *DE* (compressive):

Spans, ft	LP, ft	$L_{AB}' = -1.294V_c$, lb	$L_{AB}'' = -1.074H_c - 0.161H_g$, lb	$L_{AB} = L_{AB}' + L_{AB}''$, lb
600	1200	−2901	−886 − 88 = −974	−3875
700	1400	−3385	−1034 − 102 = −1136	−4521
800	1600	−3868	−1181 − 117 = −1298	−5166
900	1800	−4352	−1330 − 131 = −1461	−5813
1000	2000	−4836	−1477 − 146 = −1623	−6459
1100	2200	−5318	−1625 − 161 = −1786	−7104
1200	2400	−5802	−1772 − 175 = −1947	−7749
1300	2600	−6285	−1920 − 190 = −2110	−8395
1400	2800	−6769	−2069 − 204 = −2273	−9042

Crossarm *BC* and *CD* (compressive):

Spans, ft	LP, ft	$L_{CD}' = -1.294V_c$, lb	$L_{CD}'' = -1.170H_c - 1.453H_g$, lb	$L_{CD} = L_{CD}' + L_{CD}''$, lb
600	1200	−2901	−966 − 791 = −1757	−4 658
700	1400	−3385	−1127 − 922 = −2049	−5 434
800	1600	−3868	−1287 − 1054 = −2341	−6 209
900	1800	−4352	−1448 − 1186 = −2634	−6 986
1000	2000	−4836	−1609 − 1317 = −2926	−7 762
1100	2200	−5318	−1770 − 1449 = −3219	−8 537
1200	2400	−5802	−1931 − 1581 = −3512	−9 314
1300	2600	−6285	−2092 − 1713 = −3805	−10 090
1400	2800	−6769	−2253 − 1844 = −4097	−10 866

X-brace:

Spans, ft	LP, ft	$L_{KU}'' = -5.662H_c - 3.775H_g$, lb
600	1200	−4 673 − 2054 = −6 727
700	1400	−5 451 − 2396 = −7 847
800	1600	−6 230 − 2738 = −8 968
900	1800	−7 009 − 3080 = −10 089
1000	2000	−7 788 − 3422 = −11 210
1100	2200	−8 566 − 3765 = −12 331
1200	2400	−9 345 − 4107 = −13 452
1300	2600	−10 124 − 4449 = −14 573
1400	2800	−10 903 − 4791 = −15 694

Poles (at point *L*):

$$S_L = \frac{1.5V_c + V_g + 4.578H_c + 3.921H_g}{80.52\ \text{in}^2} + \left(\frac{8.67H_c + 5.78H_g}{103.60\ \text{in}^3}\right)\left(\frac{12\ \text{in}}{\text{ft}}\right) = \text{lb/in}^2$$

600-ft spans, 1200-ft LP

$$S_L = \frac{1.5(2242) + 970 + 4.578(825) + 3.921(544)}{80.52} + \left(\frac{8.67(825) + 5.78(544)}{103.60}\right)\left(\frac{12}{1}\right) = 1320\ \text{lb/in}^2$$

700-ft spans, 1400-ft LP

$$S_L = \frac{1.5(2616) + 1131 + 4.578(963) + 3.921(635)}{80.52} + \left(\frac{8.67(963) + 5.78(635)}{103.60}\right)\left(\frac{12}{1}\right) = 1541 \text{ lb/in}^2$$

800-ft spans, 1600-ft LP

$$S_L = \frac{1.5(2989) + 1293 + 4.578(1100) + 3.921(725)}{80.52} + \left(\frac{8.67(1100) + 5.78(725)}{103.60}\right)\left(\frac{12}{1}\right) = 1760 \text{ lb/in}^2$$

900-ft spans, 1800-ft LP

$$S_L = \frac{1.5(3363) + 1454 + 4.578(1238) + 3.921(816)}{80.52} + \left(\frac{8.67(1238) + 5.78(816)}{103.60}\right)\left(\frac{12}{1}\right) = 1980 \text{ lb/in}^2$$

1000-ft spans, 2000-ft LP

$$S_L = \frac{1.5(3737) + 1616 + 4.578(1375) + 3.921(907)}{80.52} + \left(\frac{8.67(1375) + 5.78(907)}{103.60}\right)\left(\frac{12}{1}\right) = 2200 \text{ lb/in}^2$$

1100-ft spans, 2200-ft LP

$$S_L = \frac{1.5(4110) + 1777 + 4.578(1513) + 3.921(997)}{80.52} + \left(\frac{8.67(1513) + 5.78(997)}{103.60}\right)\left(\frac{12}{1}\right) = 2420 \text{ lb/in}^2$$

1200-ft spans, 2400-ft LP

$$S_I = \frac{1.5(4484) + 1939 + 4.578(1650) + 3.921(1088)}{80.52} + \left(\frac{8.67(1650) + 5.78(1088)}{103.60}\right)\left(\frac{12}{1}\right) = 2640 \text{ lb/in}^2$$

1300-ft spans, 2600-ft LP

$$S_L = \frac{1.5(4857) + 2101 + 4.578(1788) + 3.921(1179)}{80.52} + \left(\frac{8.67(1788) + 5.78(1179)}{103.60}\right)\left(\frac{12}{1}\right) = 2861 \text{ lb/in}^2$$

1400-ft spans, 2800-ft LP

$$S_L = \frac{1.5(5231) + 2262 + 4.578(1926) + 3.921(1269)}{80.52} + \left(\frac{8.67(1926) + 5.78(1269)}{103.60}\right)\left(\frac{12}{1}\right) = 3081 \text{ lb/in}^2$$

Poles (at point N):

$$S_N = \frac{1.5V_c + H_g + 8.581H_c + 6.589H_g}{176.98 \text{ in}^2} + \left(\frac{11.14H_c + 7.43H_g}{335.36 \text{ in}^3}\right)\left(\frac{12 \text{ in}}{\text{ft}}\right) = \text{lb/in}^2$$

600-ft spans, 1200-ft LP

$$S_N = \frac{1.5(2242) + 970 + 8.581(825) + 6.589(544)}{176.98} + \left(\frac{11.14(825) + 7.43(544)}{335.36}\right)\left(\frac{12}{1}\right) = 558\ \text{lb/in}^2$$

700-ft spans, 1400-ft LP

$$S_N = \frac{1.5(2616) + 1131 + 8.581(963) + 6.589(635)}{176.98} + \left(\frac{11.14(963) + 7.43(635)}{335.36}\right)\left(\frac{12}{1}\right) = 651\ \text{lb/in}^2$$

800-ft spans, 1600-ft LP

$$S_N = \frac{1.5(2989) + 1293 + 8.581(1100) + 6.589(725)}{176.98} + \left(\frac{11.14(1100) + 7.43(725)}{335.36}\right)\left(\frac{12}{1}\right) = 744\ \text{lb/in}^2$$

900-ft spans, 1800-ft LP

$$S_N = \frac{1.5(3363) + 1454 + 8.581(1238) + 6.589(816)}{176.98} + \left(\frac{11.14(1238) + 7.43(816)}{335.36}\right)\left(\frac{12}{1}\right) = 837\ \text{lb/in}^2$$

1000-ft spans, 2000-ft LP

$$S_N = \frac{1.5(3737) + 1616 + 8.581(1375) + 6.589(907)}{176.98} + \left(\frac{11.14(1375) + 7.43(907)}{335.36}\right)\left(\frac{12}{1}\right) = 930\ \text{lb/in}^2$$

1100-ft spans, 2200-ft LP

$$S_N = \frac{1.5(4110) + 1777 + 8.581(1513) + 6.589(997)}{176.98} + \left(\frac{11.14(1513) + 7.43(997)}{335.36}\right)\left(\frac{12}{1}\right) = 1023\ \text{lb/in}^2$$

1200-ft spans, 2400-ft LP

$$S_N = \frac{1.5(4484) + 1939 + 8.581(1650) + 6.589(1088)}{176.98} + \left(\frac{11.14(1650) + 7.43(1088)}{335.36}\right)\left(\frac{12}{1}\right) = 1116\ \text{lb/in}^2$$

1300-ft spans, 2600-ft LP

$$S_N = \frac{1.5(4857) + 2101 + 8.581(1788) + 6.589(1179)}{176.98} + \left(\frac{11.14(1788) + 7.43(1179)}{335.36}\right)\left(\frac{12}{1}\right) = 1209\ \text{lb/in}^2$$

1400-ft spans, 2800-ft LP

$$S_N = \frac{1.5(5231) + 2262 + 8.581(1926) + 6.589(1269)}{176.98} + \left(\frac{11.14(1926) + 7.43(1269)}{335.36}\right)\left(\frac{12}{1}\right) = 1302\ \text{lb/in}^2$$

Table 27 shows a summary of loads in the structure members for various span lengths and low point distances.

Table 27.–*Summary of loads in structure members for various span lengths and low-point distances (U.S. customary example 3)*

Member	Position	SAS/2, ft								
		600	700	800	900	1 000	1 100	1 200	1 300	1 400
		LP, ft								
		1 200	1 400	1 600	1 800	2 000	2 200	2 400	2 600	2 800
Adjustable braces, lb	AG & EF	3 855	4 497	5 138	5 782	6 425	7 066	7 708	8 351	8 993
Nonadjustable braces, lb	GC & FC	3 532	4 121	4 709	5 298	5 887	6 475	7 064	7 652	8 240
Crosstie, lb	GF	1 451	1 693	1 934	2 176	2 418	2 659	2 901	3 142	3 384
Crossarm (compressive), lb	AB & DE	3 875	4 521	5 166	5 813	6 459	7 104	7 749	8 395	9 042
Crossarm (compressive), lb	BC & CD	4 658	5 434	6 209	6 986	7 762	8 537	9 314	10 090	10 866
X-brace, lb	KU & LT	6 727	7 847	8 968	10 089	11 210	12 331	13 452	14 573	15 694
Pole, lb/in^2	L	1 320	1 541	1 760	1 980	2 200	2 420	2 640	2 861	3 081
Pole, lb/in^2	N	558	651	744	837	930	1 023	1 116	1 209	1 302

26. Structure Spotting.–*Structure spotting* **is a term used for the process of determining the location, height, and type of transmission line structures on the plan and profile drawings. For wood-pole structures, the amount of guying and bracing is also determined for each location.**

(a) ***Data and Equipment Required.*****–The following data and equipment are required for determining the locations of structures on a transmission line:**

- **Plan and profile drawings of the transmission line. These drawings are prepared by the field forces.**
- **A sag template made to the plan-profile scales for the specified conductor, ruling span, and loading conditions.**
- **The necessary structure limitation and guying charts, and a conductor height table or template showing the conductor height above ground at the structure for the various structure types and heights.**
- **Required conductor clearances over ground, railroads, highways, communication circuits, and other power lines. These clearances should be calculated in accordance with the latest edition of the National Electrical Safety Code or the applicable State or municipal code.**

(b) ***Process of Spotting.*****–Figure 109 shows the details of the sag template, and figure 110 is a typical plan and profile drawing with the sag template superimposed showing the method of using it for spotting structures. Figure 110 also shows the method of using the 15.5 °C (60 °F) curve of the template to determine the proper conductor and structure heights. The curve labeled "15.5 °C (60 °F) Final" represents the conductor position. The lower two curves, marked "8.2-m (27-ft) clearance" and "8.8-m (29-ft) clearance" are exactly the same curves as the 15.5 °C final curve, but displaced vertically 8.2 and 8.8 m, respectively. Therefore, any point on the final curve is 8.2 m above the corresponding point on the 8.2-m clearance curve or 8.8 m above the corresponding point on the 8.8-m clearance curve. Referring again to figure 110, the 8.8-m clearance curve just touches the**

ground line of the profile. Therefore, the conductor is 8.8 m above the ground at the point where the 8.8-m clearance line touches the ground line.

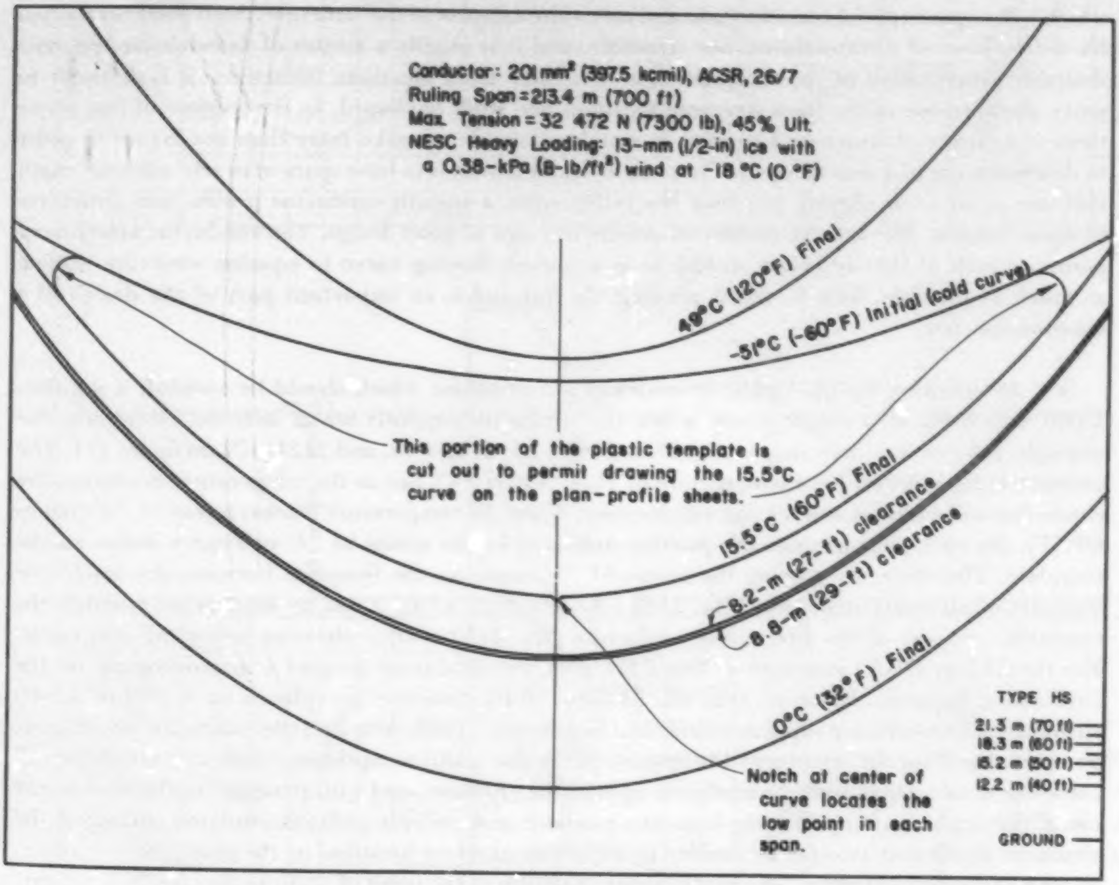

Conductor: 201 mm² (397.5 kcmil), ACSR, 26/7
Ruling Span = 213.4 m (700 ft)
Max. Tension = 32 472 N (7300 lb), 45% Ult.
NESC Heavy Loading: 13-mm (1/2-in) ice with a 0.38-kPa (8-lb/ft²) wind at −18 °C (0 °F)
49°C (120°F) Final
−51°C (−60°F) Initial (cold curve)
This portion of the plastic template is cut out to permit drawing the 15.5°C curve on the plan-profile sheets.
15.5°C (60°F) Final
8.2-m (27-ft) clearance
8.8-m (29-ft) clearance
0°C (32°F) Final
Notch at center of curve locates the low point in each span.
TYPE HS
21.3 m (70 ft)
18.3 m (60 ft)
15.2 m (50 ft)
12.2 m (40 ft)
GROUND

Figure 109.–Typical sag template (plastic) used for spotting structures. 104-D-1113.

The process of spotting usually progresses from left to right on the profile. The structure at Sta. 2083+50 on figure 110, and the spans to the left of it are spotted before the template is placed in the position described above. Please note that the station numbering referred to in this section are in U.S. customary units. After the required position of the conductor has been determined for the span to the right of the structure at Sta. 2083+50, the location and height of the next structure is selected, either by scaling or by use of a pole template. For convenience, the pole template for the various types of structures is marked on the margin of the template. For the span under discussion, the structure location selected is at Sta. 2090+20, the structure is a type HS with 18.3-m (60-ft) poles, and the span length is 204 m (670 ft). This information should be recorded on the drawing. The template is then moved to the right and the next span and structure located by repeating the process.

Although the process of spotting structures usually progresses from left to right, it is best to examine the profile for several spans ahead because there may be conditions such as line angle points, highway or railroad crossings, powerline or communication line crossings, and high or low points in the profile which will require special consideration and affect the location of the structure. Such conditions often fix the location of a transmission line structure, and it is usually a matter of determining the most desirable arrangement of the structures between these fixed locations. Sometimes it is desirable to move ahead to one of the fixed structure locations and work backward. In the sections of line where there is a choice of structure locations, it may be desirable to make more than one layout in order to determine the best arrangement. The most desirable layout is to have spans of nearly uniform length that are equal to or slightly less than the ruling span, a smooth conductor profile, and structures of equal heights. The smooth conductor profile is a sign of good design. The conductor attachment points at each of the structures should lie in a smooth flowing curve to equalize structure loading as much as possible. This is called *grading the line* and is an important part of the design of a transmission line.

(c) *Determining Uplift.*–Uplift, or upstrain, is a condition which should be avoided, if possible. Uplift may occur in a rough profile where the conductor supports are at different elevations. For example, refer to the three structures at Sta. 2105+35, 2112+40, and 2121+70 on figure 111. The conductor sag is drawn for a temperature of 15.5 °C (60 °F), but as the temperature decreases, the conductor will contract and the sag will decrease. When the temperature reaches minus 51 °C (minus 60 °F), the conductor assumes the position indicated by the minus 51 °C *cold* curve shown on the template. Therefore, by placing the minus 51 °C curve on the template between the conductor supports of alternate structures (Sta. 2105+35 and 2121+70), it can be determined whether the conductor support of the intermediate structure (Sta. 2112+40) is above or below the cold curve. For the 21.3-m (70-ft) structure at Sta. 2112+40, the conductor support is approximately on the cold curve. Suppose, however, that the 21.3-m (70-ft) structure is replaced by a 19.8-m (65-ft) structure. The conductor support would then be below the cold curve and the conductor would exert an upward pull on the structure–this upward pull is the *uplift* or *upstrain.* Uplift at a structure will cause the conductor to pull the insulators up into the crossarm, and with pin-type insulators it might cause the conductor to pull away from the insulator and possibly pull the insulator pin out of the crossarm. Uplift may possibly be avoided by adjusting structure locations on the plan-profile drawing, to take advantage of terrain, by using a higher structure at the point of uplift or by attaching weights to the conductor. If these methods fail, then the conductor must be dead-ended. Structures should not be located at uplift points if it can be avoided because the only function of such a structure is to hold the conductors against wind pressure and sometimes to support a short length of the conductors during hot weather.

(d) *Insulator Sideswing.*–Suspension insulators are subject to sideswing caused by horizontal wind pressure. Conductor clearance to the structure is reduced by insulator sideswing, so it is necessary to limit the sideswing in order to maintain proper conductor insulation. The horizontal wind pressure that tends to swing an insulator suspended on a structure is equal to one-half the total wind pressure on the conductor in the two adjacent spans. The vertical force that tends to keep the insulator string from swinging is equal to the force of the conductor supported by the insulator string plus one-half the force of the insulator string. The length of conductor supported by the insulator string is equal to the distance between the conductor low points of the adjacent spans. On rough terrain where each of the adjacent spans fall rapidly away from the structure, the conductor low points, as indicated

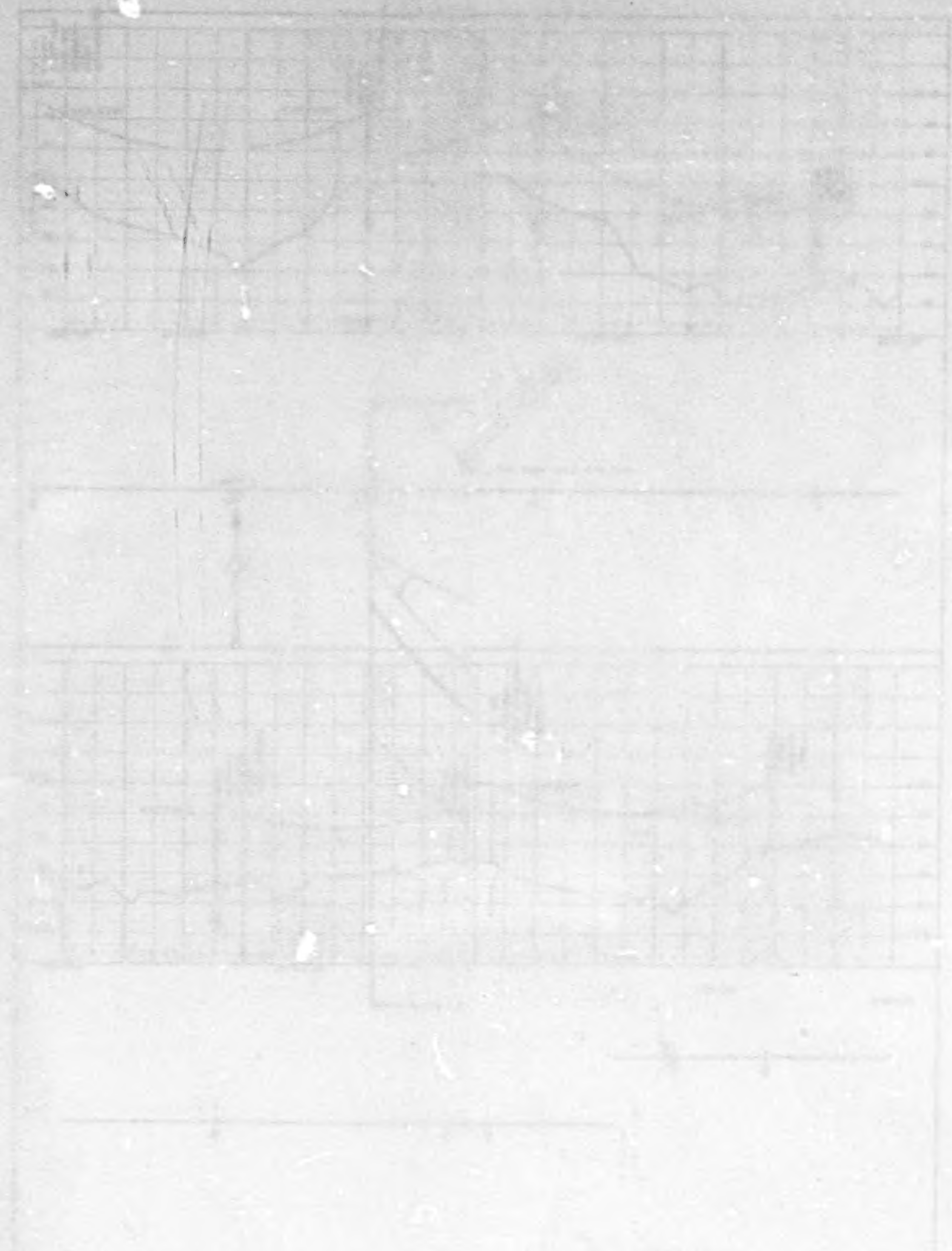


Figure [illegible] chart and [illegible]

[illegible]

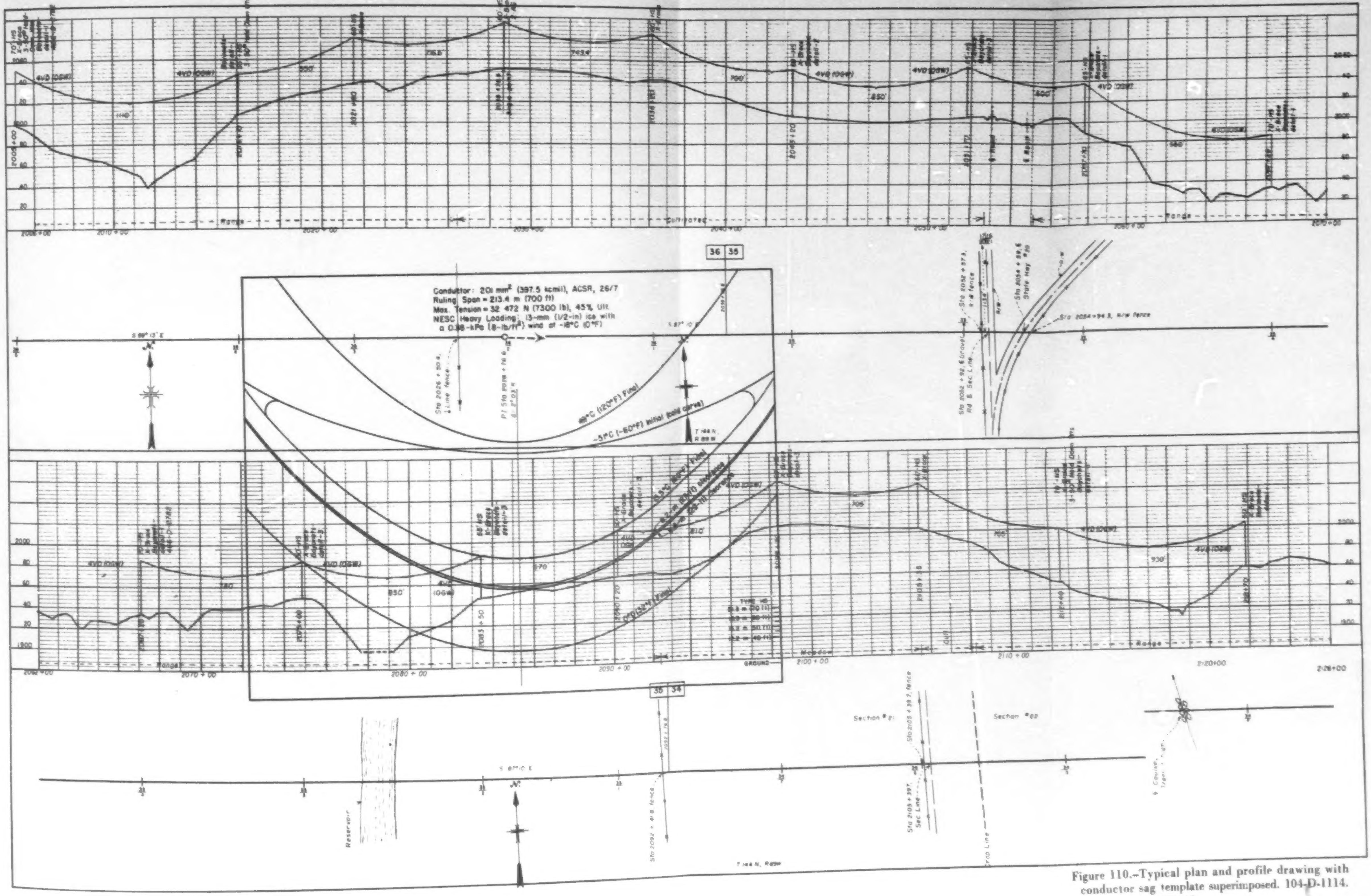

Conductor: 201 mm² (397.5 kcmil), ACSR, 26/7
Ruling Span = 213.4 m (700 ft)
Max. Tension = 32 472 N (7300 lb), 45% Ult
NESC Heavy Loading: 13-mm (1/2-in) ice with
a 0.38-kPa (8-lb/ft²) wind at -18°C (0°F)
49°C (120°F) Final
-51°C (-60°F) Initial (bold curve)
0°C (32°F) Final
4VD (OGW)
Range
Cultivated
Meadow
Reservoir
Section #21
Section #22
T 144 N, R 89 W
GROUND
2080 + 00
2090 + 00
2100 + 00
2110 + 00
2120+00
2126+00
2070 + 00
2010 + 00
2020 + 00
2030 + 00
2040 + 00
2050 + 00
2060 + 00
2070+00
36 35
35 34

Figure 110.–Typical plan and profile drawing with conductor sag template superimposed. 104-D-1114. From Dwg. 466-D-102.

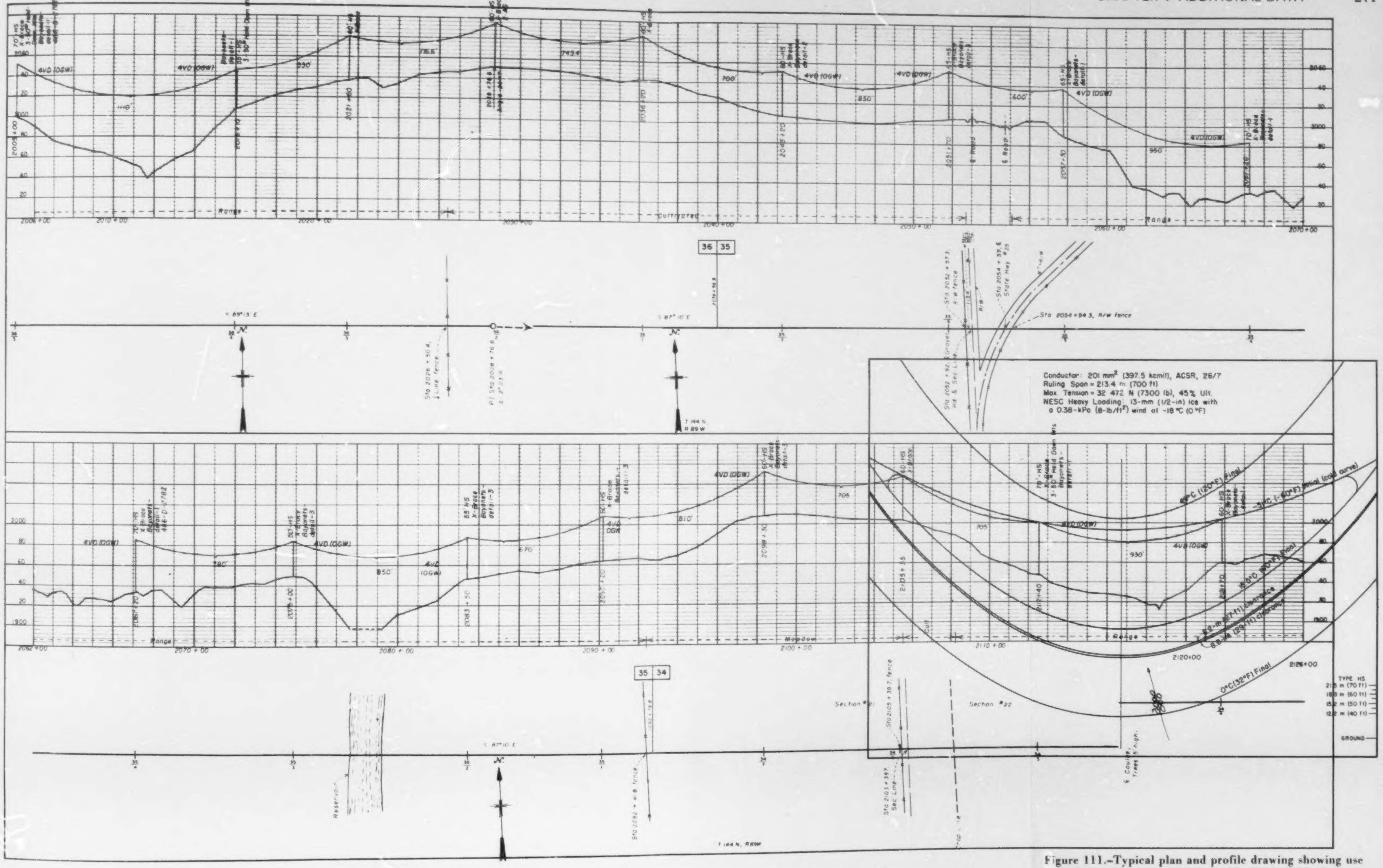

Conductor: 201 mm² (397.5 kcmil), ACSR, 26/7
Ruling Span = 213.4 m (700 ft)
Max. Tension = 32 472 N (7300 lb), 45% Ult.
NESC Heavy Loading: 13-mm (1/2-in) ice with a 0.38-kPa (8-lb/ft²) wind at -18 °C (0 °F)
49°C (120°F) Final
-51°C (-60°F) Initial (cold curve)
15.5°C (60°F) Final
8.2-m (27-ft) clearance
8.8-m (29-ft) clearance
0°C(32°F) Final
TYPE HS
21.3 m (70 ft)
18.3 m (60 ft)
15.2 m (50 ft)
12.2 m (40 ft)
GROUND
4VD (OGW)
Range
Cultivated
Meadow
Reservoir
Section #21
Section #22
Sta 2054 + 94.3, R/w fence
T 144 N, R 89 W
2006 + 00
2010 + 00
2020 + 00
2030 + 00
2040 + 00
2050 + 00
2060 + 00
2070 + 00
2080 + 00
2090 + 00
2100 + 00
2110 + 00
2120+00
2126+00
36 35
35 34

Figure 111.–Typical plan and profile drawing showing use of sag template in determining uplift. 104-D-1115. From Dwg. 466-D-102.

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by the conductor template, may fall outside of the adjacent spans. However, the distance between the low points is still the length of conductor to be considered as acting vertically to hold the insulator from swinging. Too much low-point distance can cause a failure in the insulators, the hardware, or the structure. To determine whether the sideswing of the insulators is within allowable limits, the distance between the low points of the adjacent spans is measured on the plan-profile. This value is then checked against the sum of adjacent spans on the suspension structure limitation chart. If the point so defined falls within the area in which the specified structure type may be used, the value of insulator sideswing will be within the prescribed limits. If the point falls outside this area, the insulator sideswing will be greater than allowable, and some correction is necessary. Structure heights might be adjusted to provide more low-point distance, weights could be added at the bottom of the insulator strings, or another type of structure could be used.

(e) *General Instructions.*–Instructions regarding span lengths and structure heights are given in the design instructions for each transmission line.

On all wood-pole lines, class 3 poles are normally used for pole lengths of 13.7 m (45 ft) or less; class 2 poles are normally used for lengths of 15.2 m (50 ft) and over. Class 1 poles are used for extra long spans, for extra tall structures, or where additional strength is needed for any reason.

The proper type of structure, as indicated by the structure limitation chart, should be used at a line angle in a transmission line. The correct number of guys, as shown on the guying charts, should be used for wood-pole structures.

In California, all crossings over railroads, major highways, major communication circuits, and major powerlines should be provided with sufficient clearance to maintain the clearance required by a broken conductor in either of the spans adjacent to the crossing span. Other states are governed by the NESC rules which, in the latest edition (1977), do not require broken conductor considerations.

It is our policy to provide NESC required clearance over railroads, major highways, major powerlines, and major communication lines for broken conductor conditions on transmission lines of 230 kV and above.

When strain- or pin-type structures are used on both sides of a crossing, it is not necessary to allow extra clearance for broken conductors. For lower voltages, when suspension-type structures are used on both sides of a crossing, the increased sag in the crossing span due to a broken conductor in an adjacent span is not enough to seriously decrease the clearance in most cases.

River or lake crossings involving special structures or long spans are to be handled as special studies.

When it is necessary to use spans longer than approximately 1.7 times the ruling span or shorter than one-half the ruling span, the conductors should be dead-ended at both ends of the span and sagged to a special ruling span.

Whenever the terrain slopes across the right-of-way, sufficient clearance should be maintained under the outside conductor on the high side to meet all requirements.

The maximum tension in conductors and overhead ground wires under full load should normally be reduced approximately 50 percent in the span terminating on the substation or switchyard structure. Other policies regarding substations and switchyards are:

1. It is Bureau policy to install self-supporting structures (no guys) within 183 m (600 ft) of a substation or switchyard. In general, this means that the structure adjacent to the substation

or switchyard will be a steel structure capable of accepting the unbalanced tensions in the conductor and overhead ground wire due to the slack span into the yard.

2. When the overhead ground wire tension is reduced in a span where the conductor tension is not reduced, sufficient midspan clearance between the conductors and overhead ground wires should be maintained. The amount of reduction of conductor and overhead ground wire tensions may be varied to meet the requirements of the structural design of the substation or switchyard and any special crossing requirements such as railroads, roads, and power or communication lines. The method of approach to the substation or switchyard should be discussed with the design group that is designing the steel structures before proceeding with the final design of the transmission line.

3. The deflection angle in the transmission line at the substation or switchyard structure should be made as small as possible. It is preferred that this angle be less than 10° because a larger deflection angle reduces the clearance and imposes additional transverse load on the substation or switchyard structure.

On wood-pole lines where sandy soil or other soil with poor bearing characteristics is encountered, all guyed structures should have a separate anchorplate for each guy strand.

27. Right-of-Way and Building Clearance.–Right-of-way is a very important consideration in transmission line design. Today's higher voltages, wider phase spacings, and unrestrained insulator strings require a wider right-of-way and greater clearances than ever before. A right-of-way must be wide enough to give adequate clearance between conductors in a high-wind situation, and also clearance from any obstruction that may be at the edge of the right-of-way on private property. Sufficient clearance is essential to avoid flashover to trees, buildings, pole lines, and any other obstruction adjacent to the right-of-way. Some of these clearance hazards are not obvious when the conductors are hanging in their no-wind position.

It is legally possible for someone to erect a structure, such as a building, at the very edge of our right-of-way, and occasionally this is done. The only way we can protect ourselves and others is to make our right-of-way wide enough to provide a minimum electrical clearance between the outer conductor, at a maximum wind condition of 0.43 kPa (9 lb/ft^2), and an imaginary building with a wall on the edge of the right-of-way. Tables 28 and 29 show the horizontal distance required as clearance between a conductor and a building for various line voltages and elevations above sea level. Tables 30 through 35 show the required right-of-way for transmission lines of different voltages and ruling spans.

Sometimes there is a tendency to reduce the right-of-way width to keep costs down, but this would require shorter spans (to keep the conductors safely within the right-of-way) and the line probably would be more expensive than initially because of the additional structures required.

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Table 28.–*Minimum horizontal clearance to buildings–USBR standard for NESC light, medium, and heavy loading (metric)*

kV	Conductor	Ruling span, m	Basic clearance, m	Increase for voltage,[1] m	Increase for elevation, m	Minimum horizontal clearance to buildings,[2] m
69	84 mm² ACSR 6/1	213	3.048	-	3 percent of "increase for voltage" for each 305 m of elevation over 1006 m	3.048
		305	3.048	-		3.048
115	135 mm² ACSR 26/7	213	3.048	0.2003		3.249
		305	3.048	.2003		3.249
138	242 mm² ACSR 24/7	213	3.048	.3420		3.389
		305	3.048	.3420		3.389
161	242 mm² ACSR 24/7	213	3.048	.4836		3.532
		305	3.048	.4836		3.532
230	483 mm² ACSR 45/7	305	3.048	.9086		3.956
		366	3.048	.9086		3.956
		427	3.048	.9086		3.956
345	483 mm² ACSR 45/7 duplex	305	3.048	1.6170		4.666
		366	3.048	1.6170		4.666
		427	3.048	1.6170		4.666

[1] The increase for voltage is: $\left(\frac{kV + 5\%}{\sqrt{3}} - 50\right)(0.01016)$.

[2] At 1006-m elevation and at 15.5 °C with a 0.43-kPa wind.

Table 29.–*Minimum horizontal clearance to buildings–USBR standard for NESC light, medium, and heavy loading (U.S. customary)*

kV	Conductor	Ruling span, ft	Basic clearance, ft	Increase for voltage,[1] ft	Increase for elevation, ft	Minimum horizontal clearance to buildings,[2] ft
69	No. 4/0 AWG ACSR 6/1	700	10	–	3 percent of "increase for voltage" for each 1000 ft of elevation over 3300 ft	10.00
		1000	10	–		10.00
115	266.8 kcmil ACSR 26/7	700	10	0.66		10.66
		1000	10	0.66		10.66
138	477 kcmil ACSR 24/7	700	10	1.12		11.12
		1000	10	1.12		11.12
161	477 kcmil ACSR 24/7	700	10	1.59		11.59
		1000	10	1.59		11.59
230	954 kcmil ACSR 45/7	1000	10	2.98		12.98
		1200	10	2.98		12.98
		1400	10	2.98		12.98
345	954 kcmil ACSR 45/7 duplex	1000	10	5.31		15.31
		1200	10	5.31		15.31
		1400	10	5.31		15.31

[1] The increase for voltage is: $\left(\frac{kV + 5\%}{\sqrt{3}} - 50\right)\left(\frac{0.4}{12}\right)$.

[2] At 3300-ft elevation and at 60 °F with a 9-lb/ft² wind.

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Table 30.–*Right-of-way values–NESC light loading (metric)*

kV[1]	Conductor	Ruling span, m	Maximum conductor tension,[2] newtons per conductor	Conductor sag at 15.5 °C, mm	Insulator string length, mm	Conductor swing 0.43-kPa wind 1/3 low point		Outside phase to structure centerline, m	Minimum horizontal clearance to buildings,[3] m	Right-of-way,[4] m
						Degrees	m			
69	84 mm^2 ACSR 6/1	213	[a]12 900	3 745	869	65°19′	4.1925	3.048	3.048	21
		305	[a]12 900	7 576	869	65°19′	7.6736	3.048	3.048	28
115	135 mm^2 ACSR 26/7	213	[b]16 900	3 460	1219	63°02′	4.1705	3.658	3.249	23
		305	[a]16 400	7 116	1219	63°02′	7.4292	3.658	3.249	29
138	242 mm^2 ACSR 24/7	213	[a]24 900	3 746	1372	57°09′	4.2996	4.267	3.389	24
		305	[a]23 100	7 705	1372	57°09′	7.6255	4.267	3.389	31
161	242 mm^2 ACSR 24/7	213	[a]24 900	3 746	1676	57°09′	4.5550	5.182	3.532	27
		305	[a]23 100	7 705	1676	57°09′	7.8809	5.182	3.532	34
230	483 mm^2 ACSR 45/7	305	[a]31 100	8 964	2286	50°38′	8.6982	7.620	3.956	41
		366	[a]30 200	12 851	2286	50°38′	11.7036	7.620	3.956	47
		427	[a]29 300	17 676	2286	50°38′	15.4341	7.620	3.956	55
345	483 mm^2 ACSR 45/7 duplex	305	[a]31 100	8 964	3658	50°38′	9.7590	9.144	4.666	48
		366	[a]30 200	12 851	3658	50°38′	12.7644	9.144	4.666	54
		427	[a]29 300	17 676	3658	50°38′	16.4949	9.144	4.666	61

[1] 69 through 161 kV are H-frame wood-pole construction; 230 and 345 kV are steel tower construction.

[2] Maximum conductor tensions are limited by:

[a] 18 percent ultimate strength at 15.5 °C final, no load.

[b] 25 percent ultimate strength at −18 °C final, no load.

[3] At 1006-m elevation, and at 15.5 °C with a 0.43-kPa wind.

[4] At 1006-m elevation, and rounded off to next highest meter.

Table 31.–*Right-of-way values–NESC light loading (U.S. customary)*

kV[1]	Conductor	Ruling span, ft	Maximum conductor tension,[2] pounds per conductor	Conductor sag at 60 °F, ft	Insulator string length, ft	Conductor swing 9-lb/ft² wind 1/3 low point		Outside phase to structure centerline, ft	Minimum horizontal clearance to buildings,[3] ft	Right-of-way,[4] ft
						Degrees	ft			
69	No. 4/0 AWG ACSR 6/1	700	[a]2900	12.28	2.5	65°19′	13.43	10	10.00	70
		1000	[a]2900	24.86	2.5	65°19′	24.86	10	10.00	90
115	266.8 kcmil ACSR 26/7	700	[b]3800	11.34	4.0	63°02′	13.67	12	10.66	75
		1000	[a]3700	23.27	4.0	63°02′	24.31	12	10.66	95
138	477 kcmil ACSR 24/7	700	[a]5600	12.28	4.5	57°09′	14.10	14	11.12	80
		1000	[a]5200	25.25	4.5	57°09′	24.99	14	11.12	105
161	477 kcmil ACSR 24/7	700	[a]5600	12.28	5.5	57°09′	14.94	17	11.59	90
		1000	[a]5200	25.25	5.5	57°09′	25.83	17	11.59	110
230	954 kcmil ACSR 45/7	1000	[a]7000	29.37	7.5	50°38′	28.51	25	12.98	135
		1200	[a]6800	42.09	7.5	50°38′	38.34	25	12.98	155
		1400	[a]6600	57.89	7.5	50°38′	50.56	25	12.98	180
345	954 kcmil ACSR 45/7 duplex	1000	[a]7000	29.37	12.0	50°38′	31.99	30	15.31	155
		1200	[a]6800	42.09	12.0	50°38′	41.82	30	15.31	175
		1400	[a]6600	57.89	12.0	50°38′	54.04	30	15.31	200

[1] 69 through 161 kV are H-frame wood-pole construction; 230 and 345 kV are steel tower construction.

[2] Maximum conductor tensions are limited by:

[a] 18 percent ultimate strength at 60 °F final, no load.

[b] 25 percent ultimate strength at 0 °F final, no load.

[3] At 3300-ft elevation, and at 60 °F with a 9-lb/ft² wind.

[4] At 3300-ft elevation, and rounded off to next highest 5 feet.

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Table 32.–*Right-of-way values–NESC medium loading (metric)*

kV[1]	Conductor	Ruling span, m	Maximum conductor tension,[2] newtons per conductor	Conductor sag at 15.5 °C, mm	Insulator string length, mm	Conductor swing 0.43-kPa wind 1/3 low point		Outside phase to structure centerline, m	Minimum horizontal clearance to buildings,[3] m	Right-of-way,[4] m
						Degrees	m			
69	84 mm^2 ACSR 6/1	213	[a]15 500	4 033	869	65°19′	4.4542	3.048	3.048	22
		305	[b]17 300	7 527	869	65°19′	7.6291	3.048	3.048	28
115	135 mm^2 ACSR 26/7	213	[a]19 100	3 777	1219	63°02′	4.4531	3.658	3.249	23
		305	[b]21 300	6 947	1219	63°02′	7.2785	3.658	3.249	29
138	242 mm^2 ACSR 24/7	213	[a]26 700	4 111	1372	57°09′	4.6062	4.267	3.389	25
		305	[b]28 500	7 655	1372	57°09′	7.5835	4.267	3.389	31
161	242 mm^2 ACSR 24/7	213	[a]26 700	4 111	1676	57°09′	4.8616	5.182	3.532	28
		305	[b]28 500	7 655	1676	57°09′	7.8389	5.182	3.532	34
230	483 mm^2 ACSR 45/7	305	[b]37 400	8 948	2286	50°38′	8.6859	7.620	3.956	41
		366	[b]36 900	12 827	2286	50°38′	11.6850	7.620	3.956	47
		427	[b]36 400	17 525	2286	50°38′	15.3174	7.620	3.956	54
345	483 mm^2 ACSR 45/7 duplex	305	[b]37 400	8 948	3658	50°38′	9.7467	9.144	4.666	48
		366	[b]36 900	12 827	3658	50°38′	12.7458	9.144	4.666	54
		427	[b]36 400	17 525	3658	50°38′	16.3782	9.144	4.666	61

[1] 69 through 161 kV are H-frame wood-pole construction; 230 and 345 kV are steel tower construction.

[2] Maximum conductor tensions are limited by:

[a] 25 percent ultimate strength at −29 °C final, no load.

[b] 18 percent ultimate strength at 15.5 °C final, no load.

[3] At 1006-m elevation, and at 15.5 °C with a 0.43-kPa wind.

[4] At 1006-m elevation, and rounded off to next highest meter.

Table 33.–*Right-of-way values–NESC medium loading (U.S. customary)*

kV[1]	Conductor	Ruling span, ft	Maximum conductor tension,[2] pounds per conductor	Conductor sag at 60 °F, ft	Insulator string length, ft	Conductor swing 9-lb/ft² wind 1/3 low point		Outside phase to structure centerline, ft	Minimum horizontal clearance to buildings,[3] ft	Right-of-way,[4] ft
						Degrees	ft			
69	No. 4/0 AWG ACSR 6/1	700	[a]3500	13.16	2.5	65°19′	14.23	10	10.00	70
		1000	[b]3900	24.63	2.5	65°19′	24.65	10	10.00	90
115	266.8 kcmil ACSR 26/7	700	[a]4300	12.37	4.0	63°02′	14.59	12	10.66	75
		1000	[b]4800	22.75	4.0	63°02′	23.84	12	10.66	95
138	477 kcmil ACSR 24/7	700	[a]6000	13.49	4.5	57°09′	15.11	14	11.12	85
		1000	[b]6400	25.15	4.5	57°09′	24.91	14	11.12	100
161	477 kcmil ACSR 24/7	700	[a]6000	13.49	5.5	57°09′	15.95	17	11.59	90
		1000	[b]6400	25.15	5.5	57°09′	25.75	17	11.59	110
230	954 kcmil ACSR 45/7	1000	[b]8400	29.38	7.5	50°38′	28.51	25	12.98	135
		1200	[b]8300	42.07	7.5	50°38′	38.33	25	12.98	155
		1400	[b]8200	57.38	7.5	50°38′	50.16	25	12.98	180
345	954 kcmil ACSR 45/7 duplex	1000	[b]8400	29.38	12.0	50°38′	31.99	30	15.31	155
		1200	[b]8300	42.07	12.0	50°38′	41.81	30	15.31	175
		1400	[b]8200	57.38	12.0	50°38′	53.64	30	15.31	200

[1] 69 through 161 kV are H-frame wood-pole construction; 230 and 345 kV are steel tower construction.
[2] Maximum conductor tensions are limited by:

[a] 25 percent ultimate strength at −20 °F final, no load.
[b] 18 percent ultimate strength at 60 °F final, no load.

[3] At 3300-ft elevation, and at 60 °F with a 9-lb/ft² wind.
[4] At 3300-ft elevation, and rounded off to next highest 5 feet.

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Table 34.–*Right-of-way values–NESC heavy loading (metric)*

kV[1]	Conductor	Ruling span, m	Maximum conductor tension,[2] newtons per conductor	Conductor sag at 15.5 °C, mm	Insulator string length, mm	Conductor swing 0.43-kPa wind 1/3 low point		Outside phase to structure centerline, m	Minimum horizontal clearance to buildings,[3] m	Right-of-way,[4] m
						Degrees	m			
69	84 mm² ACSR 6/1	213	[a]18 200	5 794	869	65°19′	6.0544	3.048	3.048	25
		305	[a]18 200	12 530	869	65°19′	12.1751	3.048	3.048	37
115	135 mm² ACSR 26/7	213	[b]24 400	4 452	1219	63°02′	5.0547	3.658	3.249	24
		305	[a]24 900	9 524	1219	63°02′	9.5755	3.658	3.249	33
138	242 mm² ACSR 24/7	213	[b]33 300	4 665	1372	57°09′	5.0716	4.267	3.389	26
		305	[a]38 200	8 101	1372	57°09′	7.9582	4.267	3.389	32
161	242 mm² ACSR 24/7	213	[b]33 300	4 665	1676	57°09′	5.3270	5.182	3.532	29
		305	[a]38 200	8 101	1676	57°09′	8.2186	5.182	3.532	34
230	483 mm² ACSR 45/7	305	[c]51 100	8 954	2286	50°38′	8.6905	7.620	3.956	41
		366	[c]50 700	12 844	2286	50°38′	11.6982	7.620	3.956	47
		427	[c]50 300	17 515	2286	50°38′	15.3097	7.620	3.956	54
345	483 mm² ACSR 45/7 duplex	305	[c]51 100	8 954	3658	50°38′	9.7513	9.144	4.666	48
		366	[c]50 700	12 844	3658	50°38′	12.7590	9.144	4.666	54
		427	[c]50 300	17 515	3658	50°38′	16.3705	9.144	4.666	61

[1] 69 through 161 kV are H-frame wood-pole construction; 230 and 345 kV are steel tower construction.
[2] Maximum conductor tensions are limited by:

[a] 50 percent ultimate strength at −18 °C initial, full load.
[b] 33-1/3 percent ultimate strength at −40 °C initial, no load.
[c] 18 percent ultimate strength at 15.5 °C final, no load.

[3] At 1006-m elevation, and at 15.5 °C with a 0.43-kPa wind.
[4] At 1006-m elevation, and rounded off to next highest meter.

Table 35.–*Right-of-way values–NESC heavy loading (U.S. customary)*

kV[1]	Conductor	Ruling span, ft	Maximum conductor tension,[2] pounds per conductor	Conductor sag at 60 °F, ft	Insulator string length, ft	Conductor swing 9-lb/ft² wind 1/3 low point		Outside phase to structure centerline, ft	Minimum horizontal clearance to buildings,[3] ft	Right-of-way,[4] ft
						Degrees	ft			
69	No. 4/0 AWG ACSR 6/1	700	[a]4 100	18.95	2.5	65°19′	19.49	10	10.00	80
		1000	[a]4 100	41.00	2.5	65°19′	39.53	10	10.00	120
115	266.8 kcmil ACSR 26/7	700	[b]5 500	14.57	4.0	63°02′	16.55	12	10.66	80
		1000	[a]5 600	31.23	4.0	63°02′	31.40	12	10.66	110
138	477 kcmil ACSR 24/7	700	[b]7 500	15.47	4.5	57°09′	16.78	14	11.12	85
		1000	[a]8 600	26.54	4.5	57°09′	26.08	14	11.12	105
161	477 kcmil ACSR 24/7	700	[b]7 500	15.47	5.5	57°09′	17.62	17	11.59	95
		1000	[a]8 600	26.54	5.5	57°09′	26.92	17	11.59	115
230	954 kcmil ACSR 45/7	1000	[c]11 500	29.35	7.5	50°38′	28.49	25	12.98	135
		1200	[c]11 400	42.13	7.5	50°38′	38.37	25	12.98	155
		1400	[c]11 300	57.51	7.5	50°38′	50.26	25	12.98	180
345	954 kcmil ACSR 45/7 duplex	1000	[c]11 500	29.35	12.0	50°38′	31.97	30	15.31	155
		1200	[c]11 400	42.13	12.0	50°38′	41.85	30	15.31	175
		1400	[c]11 300	57.51	12.0	50°38′	53.74	30	15.31	200

[1] 69 through 161 kV are H-frame wood-pole construction; 230 and 345 kV are steel tower construction.

[2] Maximum conductor tensions are limited by:

[a] 50 percent ultimate strength at 0 °F initial, full load.
[b] 33-1/3 percent ultimate strength at −40 °F initial, no load.
[c] 18 percent ultimate strength at 60 °F final, no load.

[3] At 3300-ft elevation, and at 60 °F with a 9-lb/ft² wind.

[4] At 3300-ft elevation, and rounded off to next highest 5 feet.

28. Armor Rods and Vibration Dampers.–All conductors are subject to aeolian and other types of vibrations produced by the wind, which induces repeated bending stresses in the conductor and may well result in its failure. Aeolian vibrations are those of the natural frequencies which are stimulated by very steady winds of 1 to 48 km/h (1 to 30 mi/h). It is the periodically varying eddy turbulence on the leeward side of the conductor that produces the excitation. The frequencies range from 1 to possibly 100 hertz, and the amplitudes normally range from a few millimeters to 200 millimeters (a fraction of an inch to several inches), or more. The frequencies and amplitudes of aeolian vibrations are functions of the wind velocity, span length, distance between nodes, tension in the conductor, diameter of the conductor, and the conductor force per unit length. On short spans, the vibration is of extremely small amplitude and is evident only by the humming sound produced–like the *singing* of telephone lines on a clear, cold morning.

Steel reinforced aluminum conductor is comparatively light and is usually strung to fairly high tensions, so it is quite susceptible to vibration. Therefore, this type of conductor requires special protection by the use of armor rods, vibration dampers, or both.

Armor rods have some damping effect on vibration and reduce the amplitude from 10 to 20 percent; however, their greatest protective value is through the reinforcing of the conductor at the point of maximum stress. In addition to offering some protection to the conductor against vibration, the armor rods protect the conductor from burns due to flashovers. Armor rods for aluminum conductors are made of aluminum and consist of a spiral layer of short, round rods surrounding the conductor. The attachment of the conductor to its support is made in the middle of the armored length. This makes the conductor equivalent to a stranded cable of larger diameter–thereby strengthening it at the support, which is in the region of maximum bending stress.

A set of 7 to 13 rods, depending on conductor size, is required to armor a conductor. The size and length of the rods vary with the size of the conductor. Generally, because of the ease of application, and removal if necessary, preformed armor rods are used for all sizes of ACSR conductors and for both steel and Alumoweld overhead ground wires. Formed rods are manufactured with a spiral shape to fit the diameter of the conductor on which they are to be used. The ends of each rod are rounded or *parrot-billed* to reduce the chance of abraiding the conductor and the tendency for corona discharge at these points. Clips or clamps are not required on this type of armor rod. Older types of armor rods, now seldom used by the Bureau, include the straight rod and the tapered-rod types. Straight armor rods, having a constant diameter for their full length, are used for ACSR conductor sizes of 15 to 62 mm² (No. 6 AWG to No. 1/0 AWG), inclusive. Tapered armor rods are straight rods with long tapered ends and are used for 79 mm² (No. 2/0 AWG) and larger conductors. Both the straight and tapered types of rods are furnished straight and the spiral is formed around the conductor at the time of installation using special armor rod wrenches. These types of rods are held in place on the conductor by the installation of armor rod clips or clamps at each end after the spiral has been formed. Normally, armor rod clamps are used on transmission lines for voltages of 115 kilovolts and higher, and armor rod clips are used for voltages of 69 kilovolts and lower. This choice is due mostly to the possibility of corona loss off the sharper edges of the clips.

Through experience, the Bureau has found the Stockbridge-type vibration damper to be a very effective device against vibration and, when properly installed, the latest models of this type of damper will greatly reduce vibration.

We use both armor rods and vibration dampers on our transmission lines. Armor rods at conductor suspension points may be eliminated if sized clamps are used for the conductor. These clamps must be an almost perfect fit, with extremely small tolerance, to provide the desired protection against strand breakage at this stress point.

Each construction contractor is required to furnish the manufacturer's recommendations for size, application, and location of the vibration dampers that are to be furnished and installed on the transmission line. The data are checked and, if found satisfactory, are transmitted to the appropriate field office as the criteria to use for installation of the vibration dampers. The dampers are installed at a prescribed distance from the centerline of the conductor suspension clamp or from the mouth of a strain clamp or compression dead end.

If all conductors vibrated at the same frequency regardless of size, span length, tension, and wind velocity, the vibration problem could be handled quite simply. A vibration damper could be placed in the middle of the loop formed in the conductor and the problem would be solved. However, the number of possible frequencies is almost unlimited so the problem becomes more complex. A damper, to be most effective, should be located at the midpoint of a loop created in the conductor by the wind; however, the midpoint could be a node point for another frequency, and the damper would have absolutely no effect (see fig. 112).

A damper must be located in the middle third of a loop to be effective. Studies should be made so that a damper installed at the chosen location will be effective on as many probable frequencies as possible. Numerous laboratory studies have been made by manufacturers of dampers over the years. The new, more sophisticated dampers have been developed through these laboratory studies and should be applied as recommended by the manufacturer. Formulas for computing the frequency and loop length and the basic theory of vibration can be found in most physics books. Two such formulas are:

For frequency:	Metric	U.S. Customary
$f = \frac{kV}{d}$		
where f = frequency	Hz	Hz
k = a constant (for air)	51.4534	3.26
V = velocity of wind	km/h	mi/h
d = outside diameter of conductor	mm	in

For loop length:	Metric	U.S. Customary
	$L = \frac{519.64}{f}\sqrt{Tg/w}$	$L = \frac{6}{f}\sqrt{Tg/w}$
where L = loop length	mm	in
f = frequency	Hz	Hz
T = tension in conductor	N	lb
g = acceleration due to gravity	9.8066 m/s^2	32.2 ft/s^2
w = force of conductor	N/m	lb/ft

A standing wave, such as the vibration loop, is the result of two traveling waves equal in magnitude but of opposite direction of motion.

Reduction of span length and tension reduces the severity of vibration.

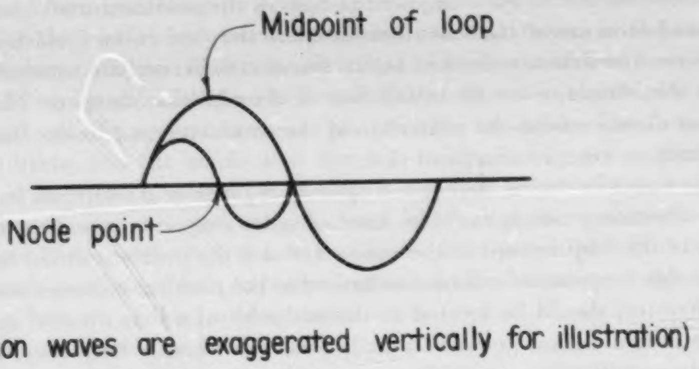
Midpoint of loop
Node point
(Vibration waves are exaggerated vertically for illustration)

Figure 112.–Schematic of vibration waves in a conductor.

Galloping or dancing conductors are large-amplitude, low-frequency vibrations. Galloping is caused by strong gusty winds blowing across irregularly ice-covered conductors. The only known methods of eliminating this phenomenon are to either prevent the ice from forming on the conductor, or to melt it off as quickly as possible after it forms and before damage occurs (see sec. 14).

29. Corona.–Corona loss on a transmission line is the result of the ionization process which takes place on the surface of conductors when the electric stress (or voltage gradient) exceeds a certain value. Corona occurs when the potential of a conductor in air is raised to such a value that the dielectric strength of the surrounding air is exceeded. Corona is visible as bluish tufts or streamers around the conductor; the visible discharge is accompanied by a hissing sound and the odor of ozone. In the presence of moisture, nitrous acid is produced and, if the corona is heavy enough, corrosion of the conductors will result. There is always a power loss with corona.

When and where will corona occur on a given transmission line? How much power loss will there be? What can be done to reduce or eliminate it? These are some of the questions that many investigators have studied over the years. Three methods of calculation by Peek [15], Carroll and Rockwell [16], and Peterson [17] are in general use in this country. The Carroll-Rockwell and Peterson formulas have been the most accurate in the low-loss region, below 3.1 kilowatt per phase kilometer (5 kilowatt per phase mile). Recent work has been directed toward corona loss in the extra-high-voltage range, and the latest available information for this range should be explored and used for calculating the expected corona loss for these higher voltages. Actually, the best method of obtaining good data is to take the data from the line being studied after it has been constructed. This is especially true of the extra-high-voltage lines, so care must be exercised to select test data and the method of calculation from a published study based on transmission line data very similar to that which you propose using.

In fair weather, corona is small up to a voltage near the disruptive voltage for a particular conductor. The calculated disruptive voltage is an indicator of corona performance. The closer the surface of a given conductor approaches a smooth cylinder, the higher the critical disruptive voltage. For the same diameter, a stranded conductor is good for about 80 to 85 percent of the voltage of a smooth conductor. Any distortion to the surface of the conductor (raised strands, burrs, scratches) will increase corona–and the higher the line voltage, the more critical these rough spots become. The size of the conductors and their spacings also have considerable effect on corona loss. Fair weather, rain, snow, hoarfrost, atmospheric pressure, and temperature must be considered when studying corona loss. Rain probably affects corona loss more than any other single factor. The presence of rain produces corona loss on a conductor at voltages as low as 65 percent of the voltage at which the same loss is observed during fair weather. The peak value of corona loss to be expected in a transmission line is very difficult, if not impossible, to determine. To do so, it would be necessary to know all of the rates of rainfall that could exist simultaneously along an entire transmission line.

In earlier years of high-voltage transmission, corona was avoided–strictly because of energy loss. In more recent years, the radio influence aspect of corona has probably become more important.

When abnormally high voltages (lightning, switching) are present, corona can affect system behavior. Corona can reduce overvoltage on long open-circuited lines, and it will attenuate both lightning voltage and switching surge.

Following is a procedure for calculating the expected corona loss on a transmission line. This procedure and related figures were taken from reference [18]. This reference used centimeters as a dimension instead of the preferred SI metric dimension of millimeters. To ensure compatibility between text and illustrations, we have chosen to present the procedure in centimeters:

Nomenclature:

P_k = corona loss, kW/km at 50 Hz (per phase)
P_c = corona loss, kW/mi at 60 Hz (per 3-phase)
E = average surface voltage gradient
E_0 = critical visual corona gradient
e = line to ground voltage, kV
F = line frequency, Hz
δ = air density factor
n = number of conductors in bundle
r = conductor radius, cm
s = spacing of conductors in bundle, cm
D = equivalent phase spacing, cm
g = mean between average and maximum surface gradient, kV/cm
g_0 = surface voltage gradient at which corona starts, kV/cm
m = conductor surface factor (assumed 0.88, average weathered conductor)

Assume:

345-kV transmission line at 1829-m (6000-ft) elevation	$e = 199.2$ kV
483-mm² (954-kcmil) ACSR,45/7 conductor (duplex)	$r = 1.48$ cm
457-mm (18-in) spacing on conductor bundle	$s = 45.72$ cm
10.06-m (33-ft) flat phase spacing	$D = 1005.84$ cm

The basic formula for reading the corona loss from the curves shown on figures 113 and 114 is:

$$\frac{P_k}{n^2\, r^2} = F\left(\frac{E}{E_0}\right)$$

$$\frac{g}{g_0} \text{ is analogous to } \frac{E}{E_0} \text{ so, } \frac{P_k}{n^2\, r^2} = F\left(\frac{g}{g_0}\right)$$

For a duplex conductor,

$$g = \frac{\left(1 + \frac{r}{s}\right) e}{(2r) \log_e \frac{D}{\sqrt{rs}}}$$

For a single conductor,

$$g = \frac{e}{r \log_e \frac{D}{r}}$$

$$g = \frac{\left(1 + \frac{1.48}{45.72}\right)(199.2)}{(2)\,(1.48) \log_e \frac{1005.84}{\sqrt{(1.48)\,(45.72)}}} = \frac{205.65}{14.23} = 14.45 \text{ kV/cm}$$

$$\text{Calculate } g_0 \text{ from } g_0 = 21.1 \text{ m } \delta^{1/2} \left(1 + \frac{0.301}{\sqrt{r}}\right)$$

Results from a high-altitude test project at Leadville, Colo. [19] concluded that the correction for air density δ varies as the one-half power in lieu of the first power as suggested by Peek [15] or the two-thirds power as indicated by Peterson's investigations [17].

$$g_o = 21.1\,(0.88)\,(0.80)^{1/2} \left(1 + \frac{0.301}{\sqrt{1.48}}\right) = 20.72 \text{ kV/cm}$$

Calculate g/g_0 and read corresponding value for P_k/n^2r^2 at 50 Hz from figure 113:

$$\frac{g}{g_o} = \frac{14.45}{20.72} = 0.70$$

From figure 113, curve *A*:

$$\frac{P_k}{n^2\, r^2} = 0.04$$

$$P_k = 0.04(2)^2\ (1.48)^2 = 0.2368 \text{ kW/km at 50 Hz (per phase)}$$

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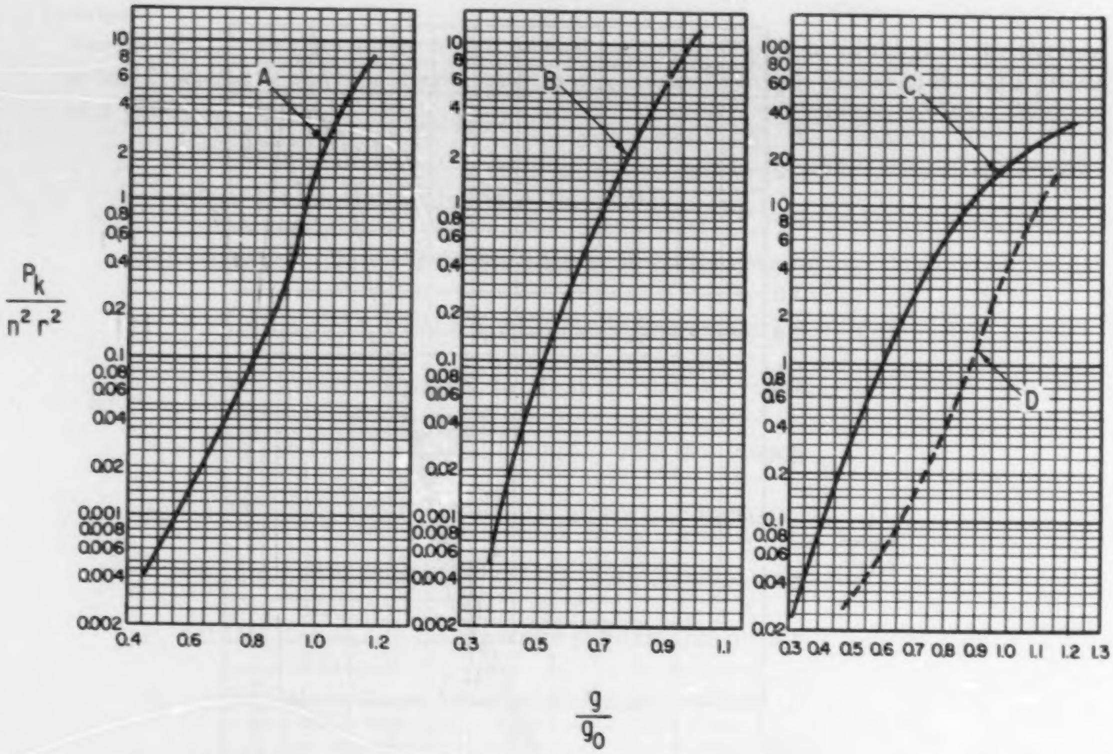

Figure 113.–Corona loss curves for (A) fair weather, (B) rainfall, (C) hoarfrost, and (D) snow. 104-D-1116. From [18].

As read from figures 113 and 114, P_k is in kilowatts per kilometer for each phase from a 50-Hz test. Because the corona loss factor is in direct proportion to frequency, the value read from the chart should be multiplied by 60/50 for a 60-Hz system. The kilometer may be changed to mile by multiplying by 1.6093, and if the loss is desired for all three phases, the answer should be multiplied by three. Combining the three factors, the figure value should be multiplied by 5.79 to obtain a loss value in kilowatts per mile for three phases for 60-Hz systems:

$$P_k = 0.2368 \text{ kW/km at 50 Hz (per phase)}$$

$$P_c = 5.79\ (0.2368) = 1.371 \text{ kW/mi at 60 Hz (per 3-phase)}$$

When rainfall is to be considered, the corona loss due to rain must be read from figure 113 using curve *B*. Similarly, for hoarfrost or snow, losses are obtained from curves *C* or *D*, respectively. Then, the two, three, or four (whichever is applicable) values for corona loss must be apportioned to make 100 percent. Taking the assigned percentages times the corresponding losses and summing these will give the expected corona loss for the line in question.

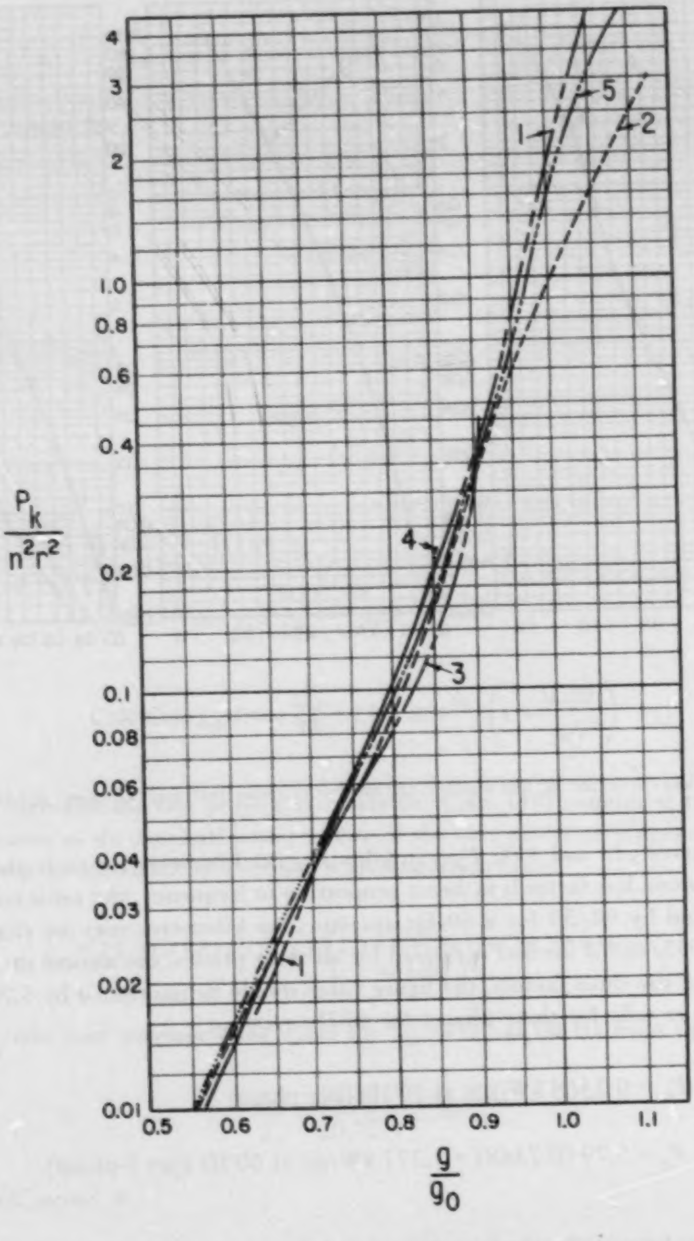

Figure 114.–Average values of corona loss under fair weather with different conductor bundles. (1) single conductor (2) two-conductor bundle (3) three-conductor bundle (4) four-conductor bundle (5) average curve. 104-D-1117. From [18].

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Example:

Assume that the line previously used is located such that 85 percent of the time the weather is fair, 5 percent of the time it rains, and 10 percent of the time it snows—all during a period of a year.

$$\frac{P_k}{n^2 r^2} = 0.04 \text{ for fair weather (curve } A\text{, fig. 113)}$$

$$P_k = 0.04(2)^2(1.48)^2 = 0.2368 \text{ kW/km at 50 Hz (per phase)}$$

$$P_c = 5.79(0.2368) = 1.371 \text{ kW/mi at 60 Hz (per 3-phase)}$$

$$\frac{P_k}{n^2 r^2} = 0.90 \text{ for rainfall (curve } B\text{, fig. 113)}$$

$$P_k = 0.90(2)^2(1.48)^2 = 7.885 \text{ kW/km at 50 Hz (per phase)}$$

$$P_c = 5.79(7.885) = 45.654 \text{ kW/mi at 60 Hz (per 3-phase)}$$

$$\frac{P_k}{n^2 r^2} = 0.15 \text{ for snow (curve } D\text{, fig. 113)}$$

$$P_k = 0.15(2)^2(1.48)^2 = 1.314 \text{ kW/km at 50 Hz (per phase)}$$

$$P_c = 5.79(1.314) = 7.608 \text{ kW/mi at 60 Hz (per 3-phase)}$$

Summation of losses times percentages:

$$(0.85)(1.371) + (0.05)(45.654) + 0.10\,(7.608) = 4.21 \text{ kW/mi at 60 Hz (per 3-phase)}$$

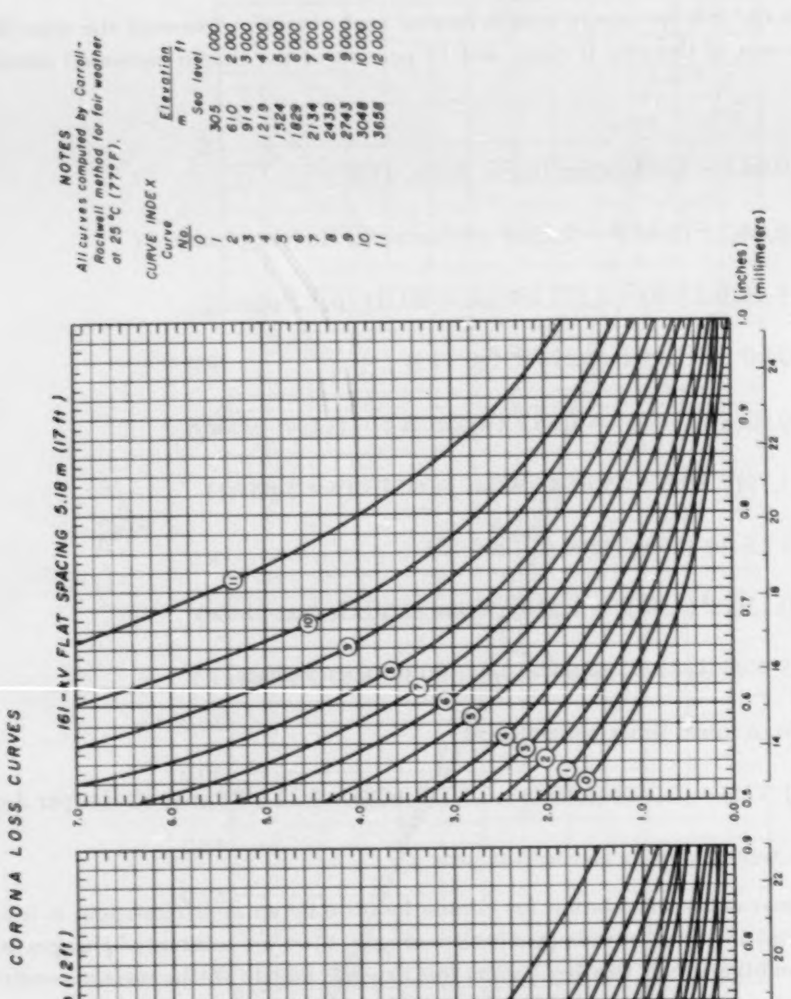
This is the average corona loss for the year.

Although this method of calculation for corona loss is only an approximation, it is apparently justified for practical purposes. As indicated in the example, there are substantial changes in the losses due to weather conditions. Fair weather corona loss depends mostly on the surface condition of the conductor. New transmission lines tend to have higher losses; however, these higher values will decrease rather rapidly with time.

Factors for various weather conditions are:

	Range	*Average value*
All conductors in rain	0.47 to 0.60	0.54
Weathered conductor in fog, mist, and snow	0.60 to 0.80	0.70
Weathered conductor in fair weather	0.80 to 0.95	0.88

Corona loss curves for different voltages are shown on figure 115. Curves are shown for different elevations and ACSR conductor sizes—from which may be determined the estimated corona loss as computed by the Carroll-Rockwell method for fair weather at 25 °C (77 °F).



NOTES
All curves computed by Carroll-Rockwell method for fair weather at 25 °C (77 °F).

CURVE INDEX

Curve No.	Elevation m	Elevation ft
0	Sea level	
1	305	1 000
2	610	2 000
3	914	3 000
4	1219	4 000
5	1524	5 000
6	1829	6 000
7	2134	7 000
8	2438	8 000
9	2743	9 000
10	3048	10 000
11	3658	12 000

Figure 115.--Corona loss curves for different voltages (sheet 1 of 2). 104-D-1118-1. From Dwg. 104-D-75.

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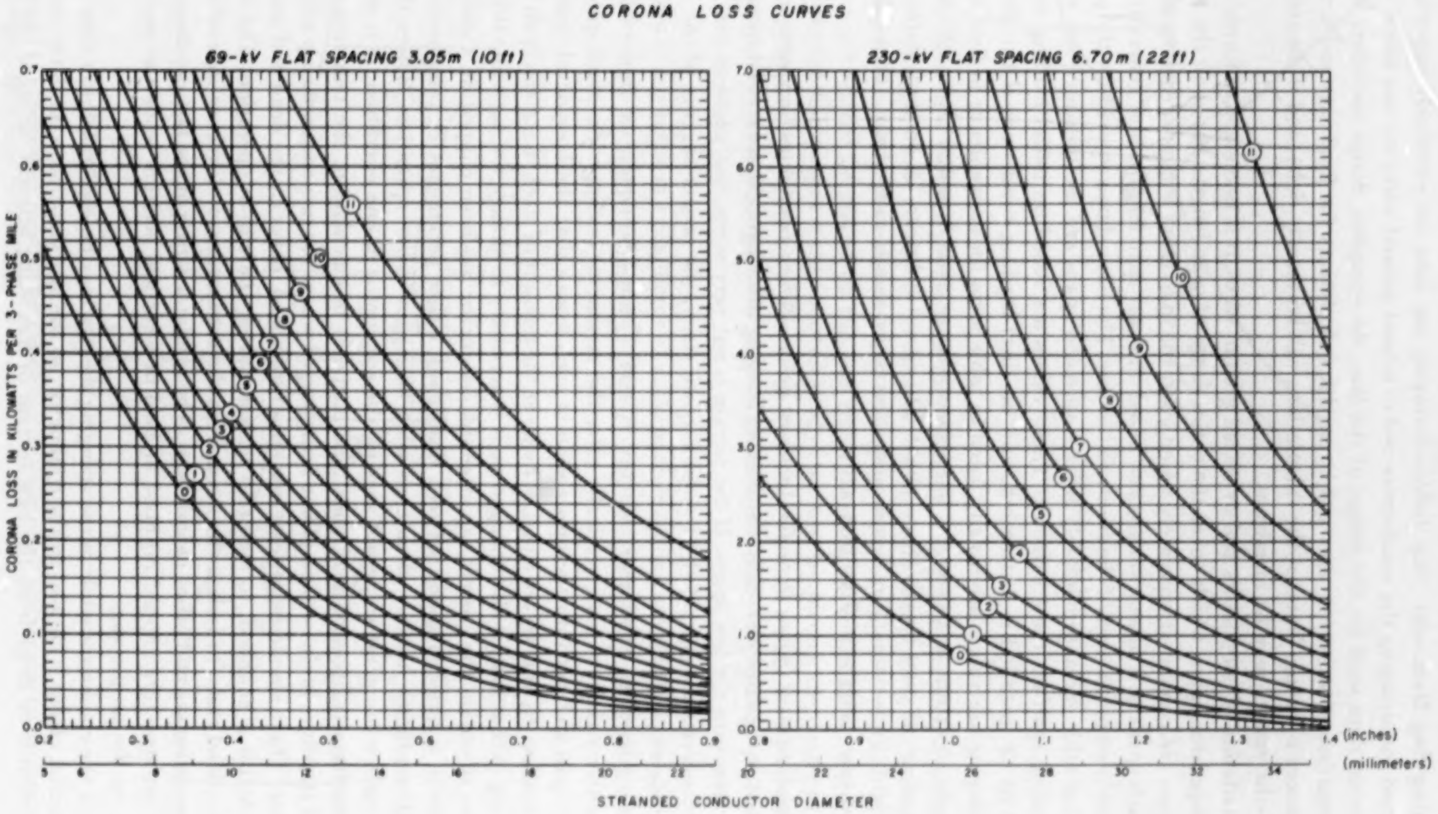
CORONA LOSS CURVES

69-kV FLAT SPACING 3.05m (10 ft)

230-kV FLAT SPACING 6.70m (22 ft)

Figure 115.–Corona loss curves for different voltages (sheet 2 of 2). 104-D-1118-2. From Dwg. 104-D-75.

30. Stringing Sag Data.–*(a) Sag Tables.*–Stringing sag data are extremely important. If the sag data furnished for stringing the conductors and overhead ground wires are not based directly on the sag and tension data used for the design of the line, the complete design including line loading studies, determination of structure sizes and strengths, calculations for final sags and tensions, and electrical clearances is wrong. None of the calculations will be exactly right, and if the stringing sags are too far off–the results may be disastrous.

For field installation of conductors and overhead ground wires, it is necessary to furnish sag tables prepared for suspension spans which cover the entire range of span lengths based on the ruling span. Dead-ended spans are computed separately based upon the individual length of each span. Stringing data for approach spans to a substation are also based on exact span lengths, but generally at a lower tension than that used on the rest of the transmission line. The basic data required for the preparation of a stringing sag table for approximately level suspension spans are the unloaded sag and tension values at the ruling span for the conductor. These values are based on initial loading conditions if the conductor to be installed is unstressed, and on final loading conditions if the conductor is prestressed. Stringing sag values are usually listed in table form for convenience in field use and are expanded to such an extent as to cover a temperature range from 0 to 120 °F in 10° increments, and to cover a range of span lengths from about 50 percent below to 50 percent above the ruling span length in 10-ft increments. For metric units, the tables should range from –18 to 49 °C in 5° increments, and span lengths in 5-m increments.

(b) *Sag and Insulator Offset Data for Inclined Spans.*–When conductor supports on adjacent structures are not at the same elevation, conductors hanging in stringing sheaves tend to run downhill from the high spans into the low spans. If the terrain is not very steep, this problem can be handled without much concern; however, if the terrain is quite steep, the proper sagging of the conductors may become complex.

On free running sheaves, conductor tensions T_1 and T_2 must be equal; see figure 116. For the suspension insulator strings to hang vertically after the conductor is clipped in, slack must be taken from the lower span and put into the upper span in such a way that the horizontal components of the conductor tension H_1 and H_2 are equal. Whenever the amount of slack in a given span is changed, the amount of sag in that span is also changed–so it is necessary to change the sag while the conductor is in the sheaves to obtain the correct sag after the conductor has been clipped in. Calculations for offsets are made in a series of spans between dead ends, either permanent or temporary, since the entire length of conductor between dead ends must be sagged in one operation. Where the distance between dead ends is too great to permit sagging the conductor in one operation, it is necessary to establish intermediate temporary dead ends. For purposes of calculation, the temporary dead end shall be the last structure in the section of line being sagged where the suspension clamp will be clipped to the conductor. There should be at least one structure ahead, between the dead end and the point where the conductor is snubbed, to maintain tension during the clip-in operation. The selection of these temporary dead ends, to isolate the steep from the comparatively level sections of line, should be such as to minimize sag and offset calculations. The insulator string of the last previous temporary dead end (the last structure clipped in) must be held in a vertical position while the next section of line is brought to the proper sag.

The tension in the conductor while in the stringing sheaves may be higher or lower than the tension after the suspension clamp is clipped to the conductor, so the last suspension insulator string clipped in may swing towards or away from the new section of line being brought to sag if the insulator is

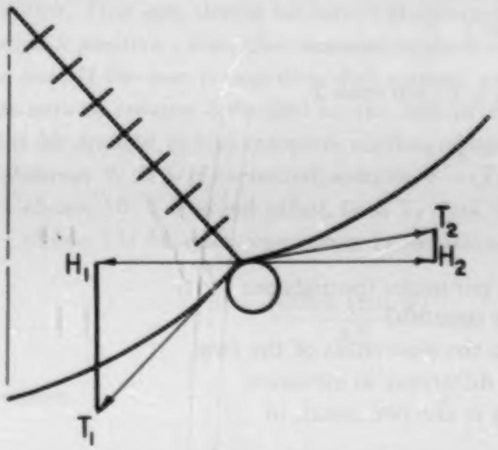

Figure 116.–Conductor tensions when using free running stringing sheaves.

not properly held in a vertical position. If the insulator is not held vertical, a serious error in the sagging and clipping in of the conductor in the new section could occur. After the conductor is brought to sheave sag by checking the corrected sag (stringing chart sag plus correction) of several spans, a reference mark should be placed on the conductor directly under the point where each insulator string is supported. Clipping in is then started at any structure by placing the center of the suspension clamp at the proper offset distance and direction from the reference mark. An explanation of a method for calculating offset and sag correction data is given in the following paragraphs.

Procedure

The tension at any point in a conductor of uniform cross section suspended in the form of a catenary is equal to the length of the ordinate of the curve at the given point times the unit force of the conductor.

At support A on figure 117:

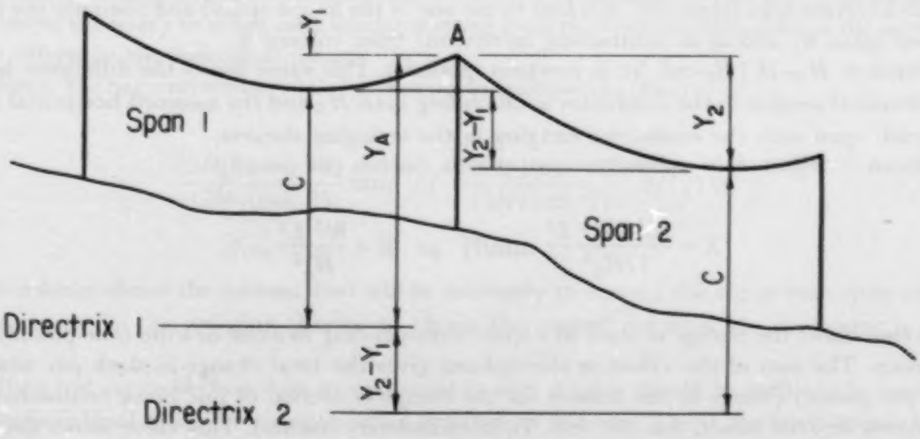

Figure 117.–Dimensions required for calculating insulator offset and sag correction data during stringing operations. 104-D-1119.

$$T_1 = WY_A \text{ in span 1}$$

$$T_2 = W(Y_A + Y_2 - Y_1) \text{ in span 2}$$

$$T_2 - T_1 = W(Y_2 - Y_1)$$

where:

W = force of conductor in newtons per meter (pounds per foot)
T_1 and T_2 = conductor tensions in newtons (pounds)
$Y_2 - Y_1$ = difference in elevation between the directrices of the two cantenaries, which is also the difference in elevation between the low points of sag in the two spans, in meters (feet)

A table with the following column headings should be made:

Column 1: Station number. This shows the survey station where each structure is located.

Column 2: Span length L, in meters (feet)

Column 3: $Y_2 - Y_1$ in meters (feet). This value shows the difference in elevation $Y_2 - Y_1$ between the low points of sags in spans adjacent to each structure. These sags should be the initial sags at the stringing temperature; however, because the difference between sags in the two spans will be essentially the same at any given temperature, $Y_2 - Y_1$ may be measured on the plan-profile sheets.

Column 4: $W(Y_2 - Y_1)$, (W) (col. 3), in newtons (pounds). This value shows the difference between the conductor tensions, $T_2 - T_1$, on the two sides of the structure.

Column 5: Assumed tension H in newtons (pounds). This value shows an assumed horizontal component H of the tension (called *horizontal tension* for convenience) in the conductor as it hangs in the stringing sheaves. For this assumption, use the initial horizontal tension of the conductor at the stringing temperature as shown on the sag-tension calculation form. Assume this tension to be in a certain span (generally, it is best to use one of the longer spans) and compute the tensions in other spans by adding or subtracting increments from column 4.

Column 6: $H_0 - H$, (H_0–col. 5), in newtons (pounds). This value shows the difference between the horizontal tension in the conductor at the ruling span H_0 and the assumed horizontal tension H in each span with the conductor hanging in the stringing sheaves.

Column 7: Offset K in millimeters per newton (inches per pound).

$$K = \frac{1000W^2 L^3}{12H_0^3} \text{ mm/N} \quad \text{or} \quad K = \frac{W^2 L^3}{H_0^3} \text{ in/lb}$$

This value shows the change in slack in a span corresponding to a one-newton (one-pound) change in tension. The sum of the values in this column gives the total change in slack per newton (or slack per pound) change in the tension for the complete section of line being considered.

Column 8: Trial offset, (col. 6) (col. 7), in millimeters (inches). This value shows the change in slack for each span corresponding to the unbalanced tensions. The algebraic sum of the values in this column is the overall change of slack for the complete section of line, based on the assumed

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tensions. This sum should be zero if the correct tension has been assumed in each span. If the sum is a positive value, that amount of slack must be subtracted from the complete section of the line. If the sum is negative, that amount must be added to the complete section of the line. The sum of column 8 divided by the sum of column 7 is the total correction in tension which must be applied to the complete section of line.

Column 9: $H_0 - H$ corrected, column 6 – (Σ col. 8/Σ col. 7), in newtons (pounds).

Column 10: Corrected offset, (col. 7) (col. 9), in millimeters (inches).

Column 11: Modulus correction in millimeters (inches)

$$\frac{1000L\ (\text{col. }9)}{AE}\ \text{mm} \quad \text{or} \quad \frac{12L\ (\text{col. }9)}{AE}\ \text{in}$$

where:

A = area of conductor in square millimeters (square inches)
E = modulus of conductor in gigapascals (pounds per square inch)

Column 12: Final correction in millimeters (inches).

$$\frac{(\Sigma\ \text{col. }10 + \Sigma\ \text{col. }11)\ (\text{col. }7)}{\Sigma\ \text{col. }7}$$

Columns 9, 10, 11, and 12 are used to make corrections in the offsets. The modulus correction (col. 11) is the change in length of the conductor with change in tension. The sum of the values in columns 10 and 11 should equal zero. If there is a remainder in either of these columns, corrections proportional to the span length must be made in column 12 to offset these remainders.

Column 13: Final offset, (col. 10 + col. 11 + col. 12), in millimeters (inches). This value shows the amount of offset required in each span.

Column 14: Sum of offsets, (running sum of col. 13), in millimeters (inches). This value shows the amount necessary to offset each insulator string from the vertical. This offset is the summation of the offsets in the individual spans.

Column 15: Sag correction while in sheaves in millimeters (feet)

$$\frac{(3H_0)(\text{col. }10)}{(2W)(\text{col. }2)}\ \text{mm} \quad \text{or} \quad \frac{(3H_0)(\text{col. }10)}{(2W)(\text{col. }2)}\ (1/12)\ \text{ft}$$

This column shows the amount that will be necessary to correct the sag in each span while the conductors are in the stringing sheaves to obtain the correct sag after the conductor is clipped in.

The offset and sag correction data as computed in such a table should be sufficiently accurate as long as the individual offset for one span is not in excess of 381 mm (15 in). For installations on very rough terrain where the offset in any one span in a section of line may exceed 381 mm, a more detailed and accurate computer program should be used instead of this simplified method. It is usually

unnecessary to consider the offset and sag correction data if, in a section of line that is being sagged in one operation, the corrections calculated are within *all* three of the following limits:

	Line conductor		Overhead ground wire	
	mm	(in)	mm	(in)
(1) Maximum summation of offsets at any structure	152	(6)	76	(3)
(2) Maximum difference between summations of offsets at adjacent structures	76	(3)	51	(2)
(3) Maximum sag correction in any span	305	(12)	305	(12)

The same procedure as described for calculating the offset and sag correction data for line conductors should be used to calculate similar data for the overhead ground wires.

A sample problem has been worked out in both metric and U.S. customary units to illustrate this procedure:

Example

Conductor: 644 mm² (1272 kcmil), ACSR, 45/7 (Bittern)

Full load conditions: 13-mm (1/2-in) radial ice with a 0.19-kPa (4-lb/ft²) wind at –18 °C (0 °F)

Maximum tension under full load conditions = 53 378 N (12 000 lb)

Initial tension at 15.5 °C (60 °F) is 26 040 N (5854 lb) with a corresponding sag of 12 485 mm (40.96 ft).

Area of conductor $A = 689$ mm² (1.068 in²)

Initial modulus of conductor $E = 46.678$ GPa (6.77x10⁶ lb/in²)

Initial $AE = 32\,162\,542$ N (7 230 360 lb)

$$H_0 = T - Ws = 26\,040 - (20.9277)(12.485) = 25\,778 \text{ N}$$
$$= 5854 - (1.434)(40.96) = 5795 \text{ lb}$$

Figures 118 and 119 show the sag and tension calculations for the given conductor, and figure 120 shows the stationing, elevations, and span lengths for the sample problem. The table described in the procedure is shown in tables 36 and 37.

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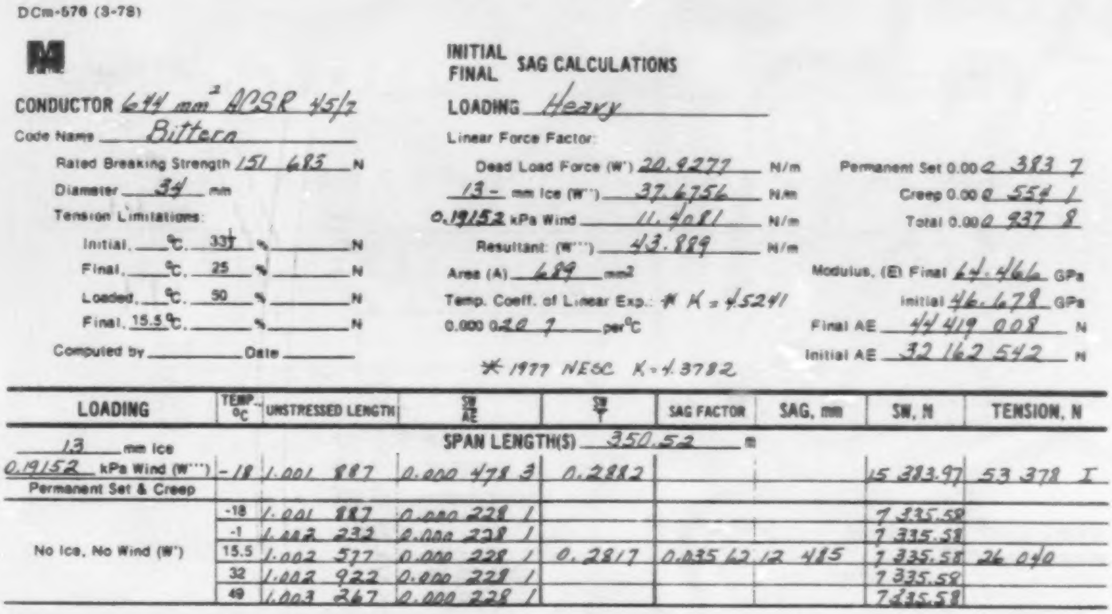


DCm-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

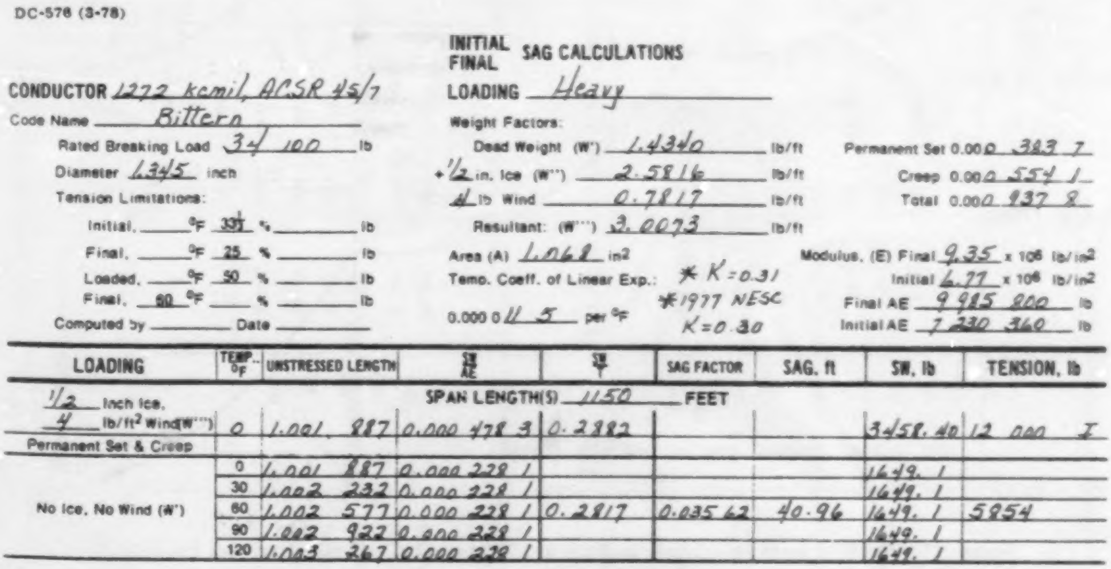
CONDUCTOR 644 mm² ACSR 45/7
Code Name Bittern
Rated Breaking Strength 151 685 N
Diameter 34 mm
Tension Limitations:
Initial, __ °C, 33⅓ % __ N
Final, __ °C, 25 % __ N
Loaded, __ °C, 50 % __ N
Final, 15.5 °C, __ % __ N
Computed by __ Date __

LOADING Heavy
Linear Force Factor:
Dead Load Force (W') 20.9277 N/m
13 - mm Ice (W'') 37.6756 N/m
0.19152 kPa Wind 11.4081 N/m
Resultant: (W''') 43.889 N/m
Area (A) 689 mm2
Temp. Coeff. of Linear Exp.: * K = 4.5241
0.000 020 7 per °C
* 1977 NESC K = 4.3782

Permanent Set 0.000 383 7
Creep 0.000 554 1
Total 0.000 937 8
Modulus, (E) Final 64.466 GPa
Initial 46.678 GPa
Final AE 44 419 008 N
Initial AE 32 162 542 N

LOADING	TEMP. °C	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, mm	SW, N	TENSION, N
			SPAN LENGTH(S) 350.52 m					
13 mm Ice 0.19152 kPa Wind (W''')	-18	1.001 887	0.000 478 3	0.2882			15 383.97	53 378 I
Permanent Set & Creep								
No Ice, No Wind (W')	-18	1.001 887	0.000 228 1				7 335.58	
	-1	1.002 232	0.000 228 1				7 335.58	
	15.5	1.002 577	0.000 228 1	0.2817	0.035 62	12 485	7 335.58	26 040
	32	1.002 922	0.000 228 1				7 335.58	
	49	1.003 267	0.000 228 1				7 335.58	

Figure 118.–Sag and tension calculation form for example problem on insulator offset and sag correction (metric).



DC-576 (3-78)

INITIAL
FINAL **SAG CALCULATIONS**

CONDUCTOR 1272 kcmil, ACSR 45/7
Code Name Bittern
Rated Breaking Load 34 100 lb
Diameter 1.345 inch
Tension Limitations:
Initial, __ °F 33⅓ % __ lb
Final, __ °F 25 % __ lb
Loaded, __ °F 50 % __ lb
Final, 60 °F __ % __ lb
Computed by __ Date __

LOADING Heavy
Weight Factors:
Dead Weight (W') 1.4340 lb/ft
+½ in. Ice (W'') 2.5816 lb/ft
4 lb Wind 0.7817 lb/ft
Resultant: (W''') 3.0073 lb/ft
Area (A) 1.068 in2
Temp. Coeff. of Linear Exp.: * K = 0.31
0.000 011 5 per °F
*1977 NESC K = 0.30

Permanent Set 0.000 383 7
Creep 0.000 554 1
Total 0.000 937 8
Modulus, (E) Final 9.35 x 10⁶ lb/in²
Initial 6.77 x 10⁶ lb/in²
Final AE 9 985 800 lb
Initial AE 7 230 360 lb

LOADING	TEMP. °F	UNSTRESSED LENGTH	$\frac{SW}{AE}$	$\frac{SW}{T}$	SAG FACTOR	SAG, ft	SW, lb	TENSION, lb
			SPAN LENGTH(S) 1150 FEET					
½ Inch Ice, 4 lb/ft² Wind (W''')	0	1.001 887	0.000 478 3	0.2882			3458.40	12 000 I
Permanent Set & Creep								
No Ice, No Wind (W')	0	1.001 887	0.000 228 1				1649.1	
	30	1.002 232	0.000 228 1				1649.1	
	60	1.002 577	0.000 228 1	0.2817	0.035 62	40.96	1649.1	5854
	90	1.002 922	0.000 228 1				1649.1	
	120	1.003 267	0.000 228 1				1649.1	

Figure 119.–Sag and tension calculation form for example problem on insulator offset and sag correction (U.S. customary).

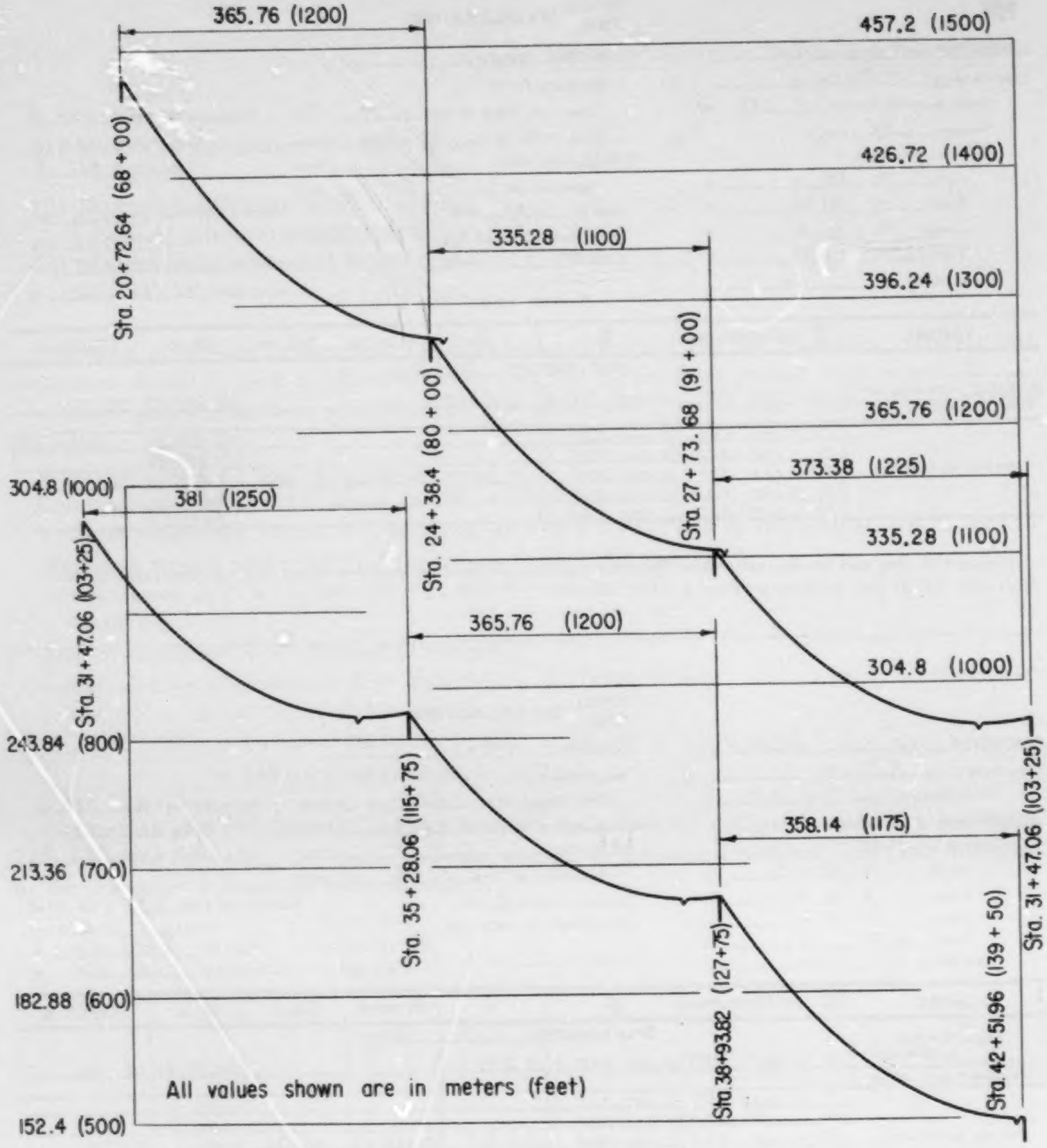

365.76 (1200)
457.2 (1500)
426.72 (1400)
335.28 (1100)
396.24 (1300)
365.76 (1200)
373.38 (1225)
335.28 (1100)
304.8 (1000)
365.76 (1200)
304.8 (1000)
381 (1250)
243.84 (800)
358.14 (1175)
213.36 (700)
182.88 (600)
152.4 (500)
Sta. 20+72.64 (68+00)
Sta. 24+38.4 (80+00)
Sta. 27+73.68 (91+00)
Sta. 31+47.06 (103+25)
Sta. 35+28.06 (115+75)
Sta. 38+93.82 (127+75)
Sta. 42+51.96 (139+50)
Sta. 31+47.06 (103+25)
All values shown are in meters (feet)

Figure 120.–Profile of spans for example problem on insulator offset and sag correction. 104-D-1120.

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Table 36.–*Data from example problem on insulator offset and sag correction (metric)*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Station	Span length L, m	$Y_2 - Y_1$, m	$W(Y_2 - Y_1)$ $W(3)$, N	Assumed H, N	$H_0 - H$, $H_0 - (5)$, N	Offset per Newton K $\frac{1000\,W^2L^3}{12H_0^3}$, mm/N	Trial offset (6) (7), mm	Corrected $H_0 - H$ $(6) - \frac{\Sigma(8)}{\Sigma(7)}$, N	Corrected offset (7) (9), mm	Modulus correction $\frac{1000\,L(9)}{AE}$, mm	Final correction $\frac{[\Sigma(10) + \Sigma(11)](7)}{\Sigma(7)}$, mm	Final offset (10) + (11) + (12), mm	Sum of offsets $\Sigma(13)$, mm	Sag correction while in sheaves $\frac{3H_0\,(10)}{2W\,(2)}$, mm
20+72.64													0	
24+38.40	365.760	-50.597	-1059	28 642	-2864	0.104 26	-299	-2445	-255	-28	0	-283	-283	-1288
27+73.68	335.280	-41.148	-861	27 583	-1805	.080 30	-145	-1386	-111	-14	0	-125	-408	-612
31+47.06	373.380	-45.110	-944	26 722	-944	.110 91	-105	-525	-58	-6	0	-64	-472	-287
35+28.06	381.000	-43.586	-912	25 778	0	.117 84	0	419	49	5	0	54	-418	238
38+93.82	365.760	-52.121	-1091	24 866	912	.104 26	95	1331	139	15	0	154	-264	702
42+51.96	358.140			23 775	2003	.097 88	196	2422	237	27	0	264	0	1223
Totals						0.615 45	-258		+1	-1				

Numbers in parentheses are column numbers.

Table 37.–*Data from example problem on insulator offset and sag correction (U.S. customary)*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Station	Span length L, ft	$Y_2 - Y_1$, ft	$W(Y_2 - Y_1)$ $W(3)$, lb	Assumed H, lb	$H_0 - H$, $H_0 - (5)$, lb	Offset per pound K $\frac{W^2L^3}{H_0^3}$, in/lb	Trial offset (6) (7), in	Corrected $H_0 - H$ $(6) - \frac{\Sigma(8)}{\Sigma(7)}$, lb	Corrected offset (7) (9), in	Modulus correction $\frac{12L\,(9)}{AE}$, in	Final correction $\frac{[\Sigma(10) + \Sigma(11)](7)}{\Sigma(7)}$, in	Final offset (10) + (11) + (12), in	Sum of offsets $\Sigma(13)$, in	Sag correction while in sheaves $\frac{3H_0\,(10)}{2W\,(2)}\left(\frac{1}{12}\right)$, ft
68+00													0	
80+00	1200	-166	-238	6439	-644	0.018 26	-11.785	-549.6	-10.04	-1.09	0.0017	-11.13	-11.1	-4.2
91+00	1100	-135	-194	6201	-406	.014 06	-5.725	-311.6	-4.38	-0.57	.0013	-4.95	-16.1	-2.0
103+25	1225	-148	-212	6007	-212	.019 42	-4.113	-117.6	-2.28	-0.24	.0018	-2.52	-18.6	-0.9
115+75	1250	-143	-205	5795	0	.020 64	0	94.4	1.95	0.20	.0019	2.15	-16.4	0.8
127+75	1200	-171	-245	5590	205	.018 26	3.751	299.4	5.47	0.60	.0017	6.07	-10.4	2.3
139+50	1175			5345	450	.017 14	7.695	544.4	9.33	1.06	.0016	10.39	0	4.0
Totals						0.107 78	-10.177		+0.05	-0.04				

Numbers in parentheses are column numbers.

31. Transmission Line Equations.–If a transmission line is surveyed from one end to the other, and there are no later reroutes; then all successive, equally spaced stations will increase uniformly in numerical notation and there will be no equations in the line. However, if two or more survey crews start work on the same line at different points, there will be one or more equations in the line. An equation will also result from a reroute of a portion of a line after a survey has been completed.

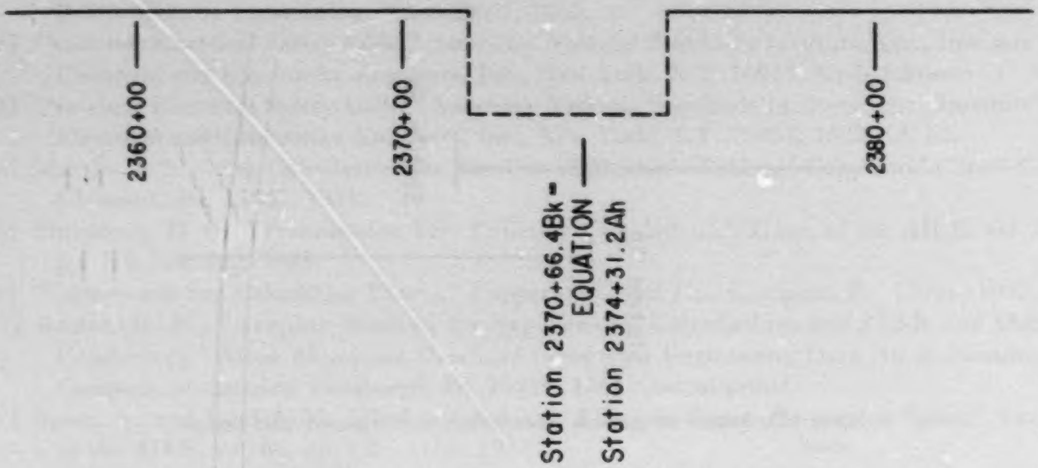
Assume that two survey crews start at opposite ends of a line and work toward each other. One crew starts at Sta. 0+00 and the other at an assumed station which is the approximate length of the line, say Sta. 4752+00. When the two crews meet at a common point on the line, they will each have a station value for that common point, but the values will be different.

Assume that the crew which started at the beginning of the line designates the common point as Sta. 2370+66.4 while the second crew designates it as Sta. 2374+31.2. The equation to identify this point is Sta. 2370+66.4Bk = Sta. 2374 + 31.2Ah. The Bk means *back* and indicates that station belongs to the part of the line behind the common point. Similarly, Ah means *ahead* and indicates that station belongs to the section of line ahead of the common point. There is a difference of 364.8 in the two designations, and the length of line will be 475 200–364.8 = 474 835.2 if there are no other equations (fig. 121). These lengths may be in meters or feet, depending on the units used.

Assume the crew which started at the beginning of the line determines that the meeting point is Sta. 2374+31.2, and the crew starting at the end of the line says the point is Sta. 2370+66.4. The equation will then read Sta. 2374+31.2Bk = Sta. 2370+66.4Ah, and the line length will then be 475 200+364.8 = 475 564.8 if there are no other equations (fig. 122).

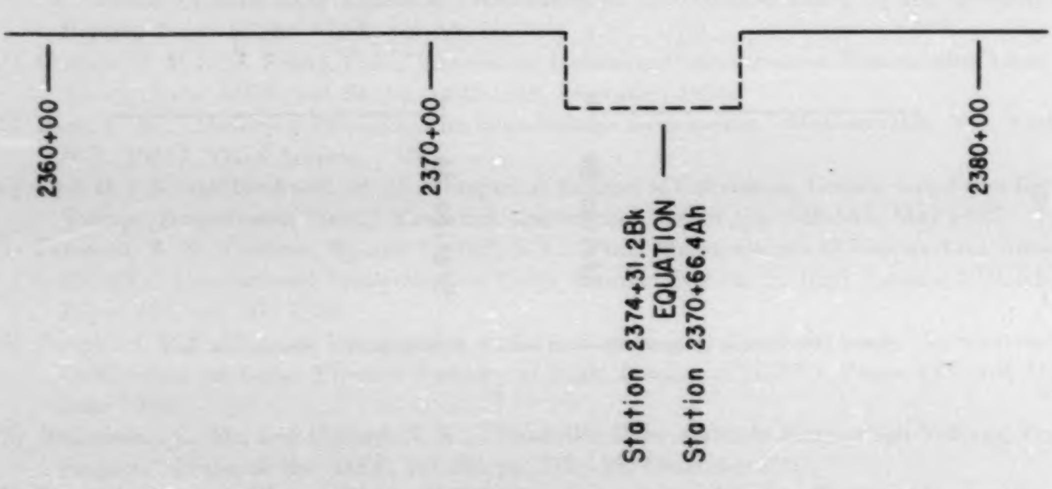
If the station back is greater than the station ahead, then there is an overlap of station designations and the length of the line is increased by the amount of overlap (fig. 123).

If the station ahead is greater than the station back, then there is a gap in the stationing and the length of the line is shortened by the value of the length of the gap (fig. 124).



2360+00
2370+00
2380+00
Station 2370+66.4Bk =
EQUATION
Station 2374+31.2Ah

Figure 121.–Stationing equation for common point on a transmission line survey, assumption No. 1.



2360+00
2370+00
2380+00
Station 2374+31.2Bk
EQUATION
Station 2370+66.4Ah

Figure 122.–Stationing equation for common point on a transmission line survey, assumption No. 2.

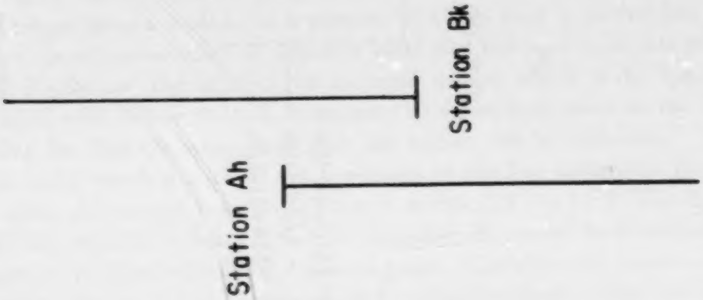

Station Bk
Station Ah

Figure 123.–Station designations when station *back* is greater than station *ahead*.

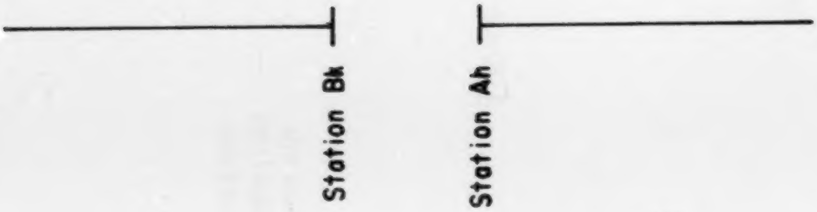

Station Bk
Station Ah

Figure 124.–Station designations when station *ahead* is greater than station *back*.

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A METHOD FOR COMPUTING TRANSMISSION LINE SAGS AND TENSIONS IN SPANS ADJACENT TO A BROKEN CONDUCTOR

A thesis by G. R. Wiszneauckas[1]

I–INTRODUCTION

Description of the Problem.–The determination of sag and corresponding tension for any conductor or cable under various conditions of temperature and loading is of basic importance in the mechanical design of a transmission line. It is of equal importance to extend this determination of sag and tension from the simple cases of symmetrical spans to the more complicated cases of nonsymmetrical and special spans, none the least of which is the case of a series of spans adjacent to a broken conductor. The determination of sags and corresponding tensions is important in this special case for the reason that it assures the designer of structure heights necessary at critical points such as railroad, highway, waterway, telephone line, or power line crossings in order to comply with national and/or local safety codes.

Purpose of Thesis.–To date, several methods or techniques have been proposed for the solution of the broken conductor problem; however, in many of the methods rather severe limitations have been imposed in that level, equal spans have been assumed for any particular problem without making corrections to account for existing asymmetries. Another somewhat undesirable aspect common to most methods is the time consuming trial-and-error procedures. These factors set forth the purpose of this thesis which is to develop a technique or method by which the sags and tensions in a series of spans adjacent to a broken conductor can be computed while accounting to some degree for the asymmetries present in any particular case and eliminating in essence the trial-and-error aspects of the methods now in use.

II–DEVELOPMENT OF A TECHNIQUE FOR ANALYZING STRESSES DUE TO A BROKEN CONDUCTOR

Study of Initial and Final Conditions.–In the broken conductor problem the initial condition, that is before the conductor breaks, is one of static equilibrium with all quantities such as sags, tensions, and span lengths known. The final condition is likewise one of static equilibrium; however, in this case all such quantities are unknown. The diagrams shown in figures 1 and 2 have been given

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to illustrate in general these initial and final conditions. In figures 1 and 2, as in those following, the insulator strings and their deflections have been shown somewhat exaggerated as compared to the other elements of the spans shown in order to present a more readable picture of the features under consideration.

A study of figure 2 reveals the complexity of the conditions which must be satisfied simultaneously in order to maintain static equilibrium after the conductor breaks. To facilitate the development of a method for treating this problem by not complicating it further, the following assumptions have been made temporarily:

(a) Level, equal spans exist before the conductor breaks.
(b) Conductor breaks at mid-span.
(c) No deflection of supporting structure as a result of the conductor breaking.
(d) No slipping of conductor in its clamps as a result of the conductor breaking.
(e) The changes in elevation of the conductor after the conductor breaks are negligible.
(f) The insulator acts as a rigid body.

After a procedure has been established for dealing with the problem under the above assumptions, criteria will be presented by which assumptions (a), (b), and (c) can be removed entirely. For most cases the assumption made under assumption (d) is valid; however, conductor clamps are sometimes set to slip at a predetermined tension, in which case this assumption may not be in order. The assumptions made under assumptions (e) and (f) are reasonable for all but very special cases.

Further study of figure 2 shows that the forces acting as a result of a conductor breaking can be resolved into two opposing horizontal forces. Herein lies the basis for the technique which has been developed.

Study of the *P* Force.–Referring again to figure 2, the horizontal force designated P is the force which retards or damps the effects of the broken conductor and may be considered as the equal and opposite of the force required to deflect an insulator string by any angle θ while a vertical load is acting. The relation between this force, P, and the vertical load can be developed from figure 3.

Again, assuming that the insulator string acts as a rigid body and also that its gravity axis is midway between the conductor and the attachment hinge, the following relations can be written: For equilibrium at any angle θ, $Wd = P'v$ or $P' = Wd/v$. Also, $\cos\theta = v/i$ and $\tan\theta = d/v = P/W$ from which $P = Wd/v$; therefore, $P = P'$. Also, $P = Wd/i\cos\theta$, which is a form more convenient for calculation. Insofar as the broken conductor problem is concerned, this relation should be interpreted as: P is the horizontal force which resists the movement of an insulator string of length i from the vertical to any angle θ while a vertical load W is acting.

Study of the *H* Force.–The horizontal force designated H in figure 2 is the horizontal component of tension acting in the conductor or cable. Insofar as the broken conductor problem is concerned, the relation between this force and a change in span length, such as might be caused by the deflection of an insulator string, is of primary importance and can be developed from figure 4 as follows: The length of conductor in the initial span is:

$$l_0 = \frac{2H_0}{w}\sinh\frac{wL_0}{2H_0}$$

The length of conductor in the span after a change of ϕ is:

$$l_1 = \frac{2\,H_1}{w} \sinh \frac{w(L_0 - \phi)}{2\,H_1}$$

The change in conductor length due to the elastic properties of the conductor in changing the tension from H_0 to H_1 is:

$$\frac{(H_0 - H_1)\,(l_0)}{AE}$$

Then, barring temperature and/or loading changes, the final conductor length must equal the initial conductor length plus or minus the elastic change in the conductor depending on whether the span length is increased or decreased, i.e.

$$l_1 = l_0 \pm \frac{(H_0 - H_1)\,(l_0)}{AE}$$

By substituting the values found above for l_1 and l_0,

$$\frac{2H_1}{w} \sinh \frac{w(L_0 - \phi)}{2H_1} = \frac{2H_0}{w} \sinh \frac{wL_0}{2H_0} \pm \frac{(H_0 - H_1)}{AE} \left(\frac{2H_0}{w}\right) \sinh \frac{wL_0}{2H_0}$$

$$\text{or} \quad \sinh \frac{w(L_0 - \phi)}{2H_1} = \frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1}$$

and solving for ϕ:

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1}\right]$$

By way of interpretation, this means that when a span of length L_0 is changed in length by an amount ϕ, the horizontal tension in the cable changes from H_0 to H_1.

The Relations Between the *P* and *H* Forces.–The relations as developed for the P and H forces become invaluable aids in the solution of the broken conductor problem, the development of which will progress from a simple special case as shown in figure 5 to a general case as shown in figure 11.

Consider first the case of a conductor breaking in a span adjacent to a dead end as shown in figure 5, which also outlines the conditions to be satisfied simultaneously in order to maintain equilibrium.

Although these conditions are simple and few, considerable effort could be expanded in using the common trial-and-error procedures to evaluate them. In contrast, the following solution has been presented:

If the P and H relations, previously developed, are plotted with a common system of coordinates as shown in figure 6, the resulting curves will intersect at some point which, upon examination, will prove to be the only point in the system which could possibly satisfy simultaneously all of the necessary and sufficient conditions for equilibrium; hence, it is the solution. Figure 6 has been given to demonstrate this solution which can be substantiated by studying any point of the H curve which lies, for instance, above the intersection with the P curve–it should be apparent that the solution point must lie on the H curve. Corresponding to the value of H at this point, note the value of ϕ and compare with the value of d which corresponds to a value of P which equals the value of H. The value of d will be less than the value of ϕ for every point so selected above the intersection, and likewise, will be greater than ϕ for every point below the intersection. Note then, that although there are any number of points or conditions for which $P = H$, there is only one–the intersection of the P and H curve–which satisfies also the other necessary condition that $d = \phi$.

As a step in the generalization of this more or less special case, consider next the case of a conductor breaking two spans away from dead end as shown in figure 7. In this case an additional set of conditions must be satisfied in order to maintain equilibrium. Referring to figure 8, it can easily be seen that the intersection of the basic P and H curves no longer satisfies all of the required conditions as in the previous case; however, these basic curves can be manipulated to obtain values which will satisfy all of the required conditions. A method for this manipulation can be derived from the trial-and-error procedures commonly used in other methods. The essentials of such a trial-and-error procedure are as follows:

(1) Referring to figure 7, assume a value for d_1 and compute the corresponding new tension which would be H_1. Also, based on the assumed value for d_1, compute the corresponding value of P_1.

(2) Compute the value of H_2 by subtracting P_1 from H_1.

(3) Knowing H_2, compute the corresponding value of ϕ_2.

(4) From this value of ϕ_2, the value of d_2 can be determined by the relation: $d_2 = \phi_2 + d_1$.

(5) P_2 can now be evaluated since it is a function of d_2. If this value for P_2 is equal to the value computed for H_2, the initial assumption for the value of d_1 is correct and all other values computed are correct; however, if this is not the case, then a new value must be selected for d_1 and the entire procedure repeated. Usually, three or four trials will bracket the correct value of d_1 which can then be found by interpolation, and the corresponding correct values for H_1, H_2, and d_2 can be computed.

Based on this procedure, a straightforward graphical analysis can be developed as follows: if all possible values for d_1 were assumed, then all possible values for H_1 and P_1 could be determined from which all possible values of H_2 could be found. This can be accomplished very easily by subtracting graphically, point by point, the abscissa values of the basic P curve from those of the basic H curve. The resulting curve then represents the locus of all possible values for H_2 with respect to d_1. In similar manner, the graphical addition of the ordinates of the newly formed H_2 curve, which represents also the locus of all possible values of d_1 to the ordinates of the basic H curve, which represents all possible values of ϕ_2, will result in forming a new curve which represents the locus of all possible values of d_2 and also represents all possible values of H_2 with respect to d_2. Now that all possible values for H_2 with respect to corresponding values of d_1 and d_2 have been defined, all

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that remains to be done is to determine which of the possible values will satisfy the required conditions. Referring again to figure 8, it should be evident that some point on the newly formed d_2 curve will satisfy the conditions required at the insulator string immediately adjacent to the break in the conductor. As in the previous case, it will be found that there are any number of points on this curve which will satisfy the necessary condition that $d_2 = \phi_2 + d_1$. By inspection, it can be seen that the intersection point of the basic P curve and the d_2 curve (point a) is the only point which can satisfy all of the necessary conditions for equilibrium at the first insulator string adjacent to the break. Further inspection will prove point b on the basic H curve to be the only point which can satisfy all of the necessary conditions for equilibrium at the second insulator string. In regard to point b, note the simple manner in which it is determined–project vertically down from point a to intersect the H_2 curve and thence horizontally to intersect the basic H curve.

The next step in the generalization of the problem would be to add another span in the series to make the dead end three spans away from the break as shown in figure 9. In this case it will be of interest to note the similarities to the two previous cases. Of special importance is the progressive and interrelated nature in which the requirements for equilibrium occur as the span in which the conductor breaks is moved away from the dead end. By comparing these requirements, it will be seen for this case that only one set of conditions is needed to maintain equilibrium in addition to those required in the previous case in which the conductor breaks two spans away from the dead end. Also, though it may not be immediately apparent, the graphical analysis as developed for the previous case can be utilized in its entirety and requires only an additional step to account for the additional requirements for equilibrium in order to provide the complete solution. This additional step is one which is in continuation of those taken in the previous case, and consists of determining from all of the possible values found for d_2, the corresponding possible value of P_2 from which all possible values of H_3 with respect to d_2 can be determined. This can be accomplished by subtracting graphically, point by point, the abscissa values of the basic P curve from the corresponding values of the d_2 curve thus forming a new curve, H_3. Then, knowing all possible values of H_3, the corresponding values of d_3 can be determined by adding graphically, point by point, the ordinates of the H_3 curve to the corresponding ordinates of the basic H curve–thus forming a new curve, d_3, which represents the locus of all possible values of H_3 with respect to d_3. The results of these manipulations have been shown in figure 10. Also indicated is the solution which is represented by points a, b, and c. These points were obtained in a manner similar to that given for the previous case and can be substantiated likewise.

Based on these special cases, a procedure for solving a general case as represented by figure 11 can be outlined as follows:

(1) Compute and plot values for the basic P and H curves as shown in figure 12.

(2) Subtract graphically, point by point, the abscissa values of the basic P curve from the abscissa values of the basic H curve to form a new curve, H_2.

(3) Add graphically, point by point, the ordinate values of the new H_2 curve to the ordinate values of the basic H curve to form a new curve, d_2.

(4) Subtract graphically, point by point, the abscissa values of the basic P curve from the abscissa values of the new d_2 curve to form a new curve, H_3.

(5) Add graphically, point by point, the ordinate values of the new H_3 curve to the ordinate values of the basic H curve to form a new curve, d_3.

(6) Continue this composition process of subtracting abscissa values of the basic P curve from those of each succeeding d curve to form new H curves, and add the ordinate values of these new H curves successively to the ordinate values of the basic H curve to form new d curves

until the d_n and H_n curves are established. The composition procedure as described above can be represented symbolically as:

$$H - P = H_2 + H = d_2 - P = H_3 + H = d_3 \;\ldots\; H_n + H = d_n$$

in which the (–) indicates point by point subtraction of abscissa values of curves, and the (+) indicates point by point addition of the ordinate values of curves.

(7) The solution is then found graphically by *stairstepping* down from the intersection of the d_n curve with the basic P curve, which defines the deflection of the insulator immediately adjacent to the conductor break and the horizontal tension in the span immediately adjacent to the conductor break, to the H_n curve and across to the d_{n-1} curve and down to the H_{n-1} curve and across to the d_{n-2} curve and down to the H_{n-2} curve, etc. until the basic H curve is reached. Each intersection of the converging stairstep with a d curve defines the deflection of the insulator string which corresponds to the subscript of the curve and also the tension in the span which is identified by the same subscript. Having established the deflections of each insulator and the tension in each span from the conductor break to the dead end, the length of each span and the corresponding sag can be computed by any standard method. The stairstep procedure as described above can be represented symbolically as:

$$\textcircled{d_n} \times P \downarrow H_n \rightarrow \textcircled{d_{n-1}} \downarrow H_{n-1} \;\ldots\; H_2 \rightarrow \textcircled{d_1}$$

in which $d_n \times P$ indicates the intersection of d_n and P curves, the vertical arrows indicate a vertical projection down from one curve to another, and the horizontal arrows indicate a horizontal projection, left to right, from one curve to another. The circles indicate intersection points of the stairstep with d curves, which points describe insulator deflections and conductor tensions.

From the procedure as outlined to this point, a question as to the physical possibility of constructing all of the indicated number of curves for a case in which the nearest dead end is a very great number of spans away from the conductor break might logically be raised. Such a question immediately suggests trying to find the limiting locus of the d_n and H_n curves. Fortunately, this can be done with a fair degree of accuracy. By following the procedure as outlined above until five or six d and corresponding H curves have been constructed, a tendency of convergence can be noted regarding the space relations of the intersection points of the d curves with the basic P curve. Upon examining these space relations closely, it will be found that a geometric series can be arranged which will very closely describe this tendency. Then, it is but a simple matter to test the series for convergence and find its sum which, if existent, will describe the space relations of the intersection point of the d_n curve. The location can be established by drawing a curve through this point and the H_0 point such that it appears to be a member of the family of curves thus far established. In many cases, this will be a straight line for practical purposes. From the d_n curve, the H_n curve is easily established by subtracting abscissa values of the basic P curve, point by point, from those of the d_n curve. By stairstepping down between these curves from the intersection point of the d_n curve with the basic P curve to the H_0 point, and noting the intersection points of the converging stairstep on the d_n curve, the insulator deflection and tension value for each span progressing away from the conductor break will be defined. These points present an interesting relation in that regardless of the distance to the nearest dead end, the effects of a conductor breaking will be damped out for practical purposes in a very few spans. This is in agreement with statements made by other authors on this subject. Figure 16 illustrates in detail a solution for a typical problem by this procedure.

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To substantiate the validity of stairstepping between only the d_n and H_n curves, reason as follows: Since the d_n and H_n curves represent in theory the limiting positions of an unlimited number of curves, it should be evident that these curves will have to be so indescribably close together that for practical purposes one could not distinquish between the d_n, the d_{n-1}, the d_{n-2}, or even the d_{n-1000} curve. Likewise, it would be equally difficult to distinguish between the H_n, the H_{n-1}, the H_{n-2}, or the H_{n-1000} curve. Therefore, it is possible for the d_n and H_n curves to represent such a great number of curves in the family that the stairstep formula previously given reduces, for practical purposes, to operating between the d_n and H_n curves. While this aspect of the analysis may appear academic only, actually it serves as the solution for the majority of preliminary problems encountered in practice since it can represent any case in which the dead end is beyond a few spans from the break in the conductor.

Another interesting and useful feature of this entire procedure is that the results can easily be checked either graphically or by inspection in a manner such as has been shown in figures 4, 6, 8, 10 or 12. In this connection, care should be taken to check the d_n intersection point with the basic P curve and the d_n and H_n curves by resolving them (that is, reversing the process of composition) far enough to ensure that the H_0 point is approached and not some other point on the horizontal force scale. This feature prompts the question of accuracy. As with the other methods, accuracy can be attained to any degree desired. With this method, curves drawn on a standard 11- by 15-inch cross-section sheet as shown in figures 16 or 17, should offer sufficient accuracy for all but very special cases.

Criteria for Removing Initial Assumptions.–The following is an outline of procedures for adjusting the method developed thus far to accommodate problems with asymmetries, such as unequal and nonsymmetrical spans, and with other variables, such as deflections in supporting structures and the point of the conductor break which were initially assumed constant. In dealing with a series of unequal and nonsymmetrical spans, it should be realized that such a series of spans is the *rule* rather than the *exception*, and that any method for dealing with problems regarding such a series of spans which does not recognize this fact and offers some means to account for it–is not doing justice to the problem.

Two criteria can be used to adjust the method developed thus far to account for such asymmetries and variables. One offers an approximate correction at the expense of very little additional work and is suitable for use in making preliminary studies and estimates. The other offers a comparatively exact solution but requires much more work and is suitable for use in connection with problems requiring a high degree of accuracy.

The approximate correction is based on the Ruling Span Theory which states, in effect, that for any series of random-length symmetrical spans, there can be found a series of equal-length symmetrical spans which will have the same horizontal tension, the same total slack, and cover the same distance as the random-length series of spans. Applying this theory to the broken conductor problem, the implications are then, that for any series of spans which might exist between a break in a conductor and the nearest dead end, there will exist one series of equal-length symmetrical spans which will best describe the characteristics of the existing series of spans. If such an equivalent series of spans can be established, the method, as developed, can be applied. In order to establish the equivalent series of spans, a means for determining the equivalent level or symmetrical span for any inclined or nonsymmetrical span will be required. Such a means has been developed by Martin[8][2] and is given by a relation as:

---

[2] Numbers in brackets refer to items in the Bibliography, section VI.

Equivalent level span length = 2 (inclined span length) – (horizontal span length). (Safe limit = 20 percent slope)

This relation makes possible the conversion of any series of spans into a series of symmetrical spans and leaves only one condition yet to be fulfilled–that of finding an equivalent series of equal length spans. This can be done by using a relation given by Still[6].

$$\text{Ruling span length} = \sqrt{\frac{L_1^3 + L_2^3 + L_3^3 + \ldots L_n^3}{L_1 + L_2 + L_3 + \ldots . L_n}}$$

The ruling span length is then the length of each span in the equivalent series of spans. Figure 16 gives the solution of a typical problem by this approximate method.

The more exact correction is accomplished by recognizing asymmetries as they actually exist and treating them as such without recourse to equivalent arrangements. Treatment of a problem on this basis requires a separate basic *P* and *H* curve for each span involved, and while possible, undue difficulties would be experienced in computing the basic *H* curves for nonsymmetrical spans. In order to alleviate these difficulties, but with little or no sacrifice in accuracy, the *H* curves can be based on the equivalent level span of each nonsymmetrical span thereby making possible the use of the *H* curve relations as previously derived. The basic *P* curves required can be computed exactly as previously outlined; however, for nonsymmetrical spans, the weight of conductor acting on each insulator must be taken as equal to the weight of conductor from low point to low point. This distance can be measured on the plan-profile sheets describing the series of spans under study. Figure 13 is given to illustrate a typical problem.

The initial assumption that the conductor break occurs at midspan can be generalized under this correction procedure by adjusting the basic *P* curve of the insulator immediately adjacent to the break to account only for the actual length of conductor from the assumed break point to the low point of the conductor in the adjacent span. In this connection, it is interesting to note that if the conductor is assumed to break next to an insulator string and if the adjacent span were inclined so that its low point would fall sufficiently far outside of the span, a negative weight or uplift would act on the insulator string which could cause it to deflect above the horizontal position which is generally considered the limiting position.

The effects of structure deflection can also be incorporated into the basic *P* curves if the relation between the structure deflection and the horizontal deflecting force is known to the extent that a descriptive curve similar in aspect to the basic *P* curve can be drawn. By adding, point by point, the ordinates of this curve to the basic *P* curve of each span, new curves describing the combined effects of insulator and structure deflections will be formed and can be used in the procedure exactly as the *P* curves are. By a similar procedure, the effects of "hinged" crossarms may also be incorporated into the basic *P* curves.

Represented in figure 14 is a solution by this criteria for the typical case shown in figure 13. The steps involved in this procedure can be outlined as follows:

(1) Compute a basic *P* curve for each insulator string to be considered, based on actual conductor weights as determined from low-point distances and based on other considerations such as structure deflections, hinged crossarms, etc.

(2) Compute a basic *H* curve for each span involved, based on the equivalent level span for each actual span.

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(3) Plot these curves in the same coordinate system.

(4) Manipulate these curves graphically by the following symbolic formula:

$$H_1 - P_1 = H_2' + H_2 = d_2 - P_2 + H_3' + H_3 = d_3$$

(5) The solution is given by the symbolic stairstep formula:

$$\enclose{circle}{d_3} \times P_3 \downarrow H_3' \rightarrow \enclose{circle}{d_2} \downarrow H_2' \rightarrow \enclose{circle}{d_1}$$

The justification for the above solution follows the same reasoning as given previously for the general case as represented in figure 11. One question which could be raised in this connection concerns the handling of a problem in which the dead end is a great distance away from the conductor break. In this case, as in previous cases considered, the effects of the broken conductor will be damped out for practical purposes in a few spans so that the first 6, 8, or 10 spans away from the break, depending on the nature of the problem, are all that need be considered.

III–SUMMARY

To summarize, the discussion presented outlines a general method or procedure based on special catenary relations for determining insulator and/or structure deflections and conductor tensions in spans adjacent to a broken conductor. Knowing these deflections and tensions, the corresponding conductor sags can be computed by the use of standard catenary relations. The method, while graphical in nature, is capable of a high degree of accuracy and is straightforward; that is, it does not involve the usual trial-and-error procedures. In appendix A-1 which follows, a typical broken conductor problem has been worked out and a comparison made of the results as obtained by this method with those as obtained by another method.

IV–APPENDIX A-1

The Solution of a Typical Broken Conductor Problem.–In the following, a typical broken conductor problem has been worked out to illustrate the techniques presented. For this purpose and to facilitate a comparison of results, the typical problem used by Bissiri and Landau[4] has been selected. The details of the problem are given in figure 15. The requirement is to find the sag and tension in span A if the conductor breaks next to insulator No. 6.

By the approximate method the procedure is as follows:

(1) Using the nomograph given in figure 18, convert the series of given spans into a series of level spans. Since all equivalent level span lengths are less than 2 feet more than the horizontal span lengths shown, all spans will be assumed level without correction.

(2) Using the Ruling Span Computation Chart given in figure 18, convert the series of level spans into a series of level equal spans. Take 970 feet as the span length for the equal level span series.

(3) Using the *H* force formula, assume values for H_1 and compute corresponding values of ϕ. These values are given in table A.

(4) Using the *P* force formula, assume values of *d* and compute corresponding values of *P*. These values are given in table B.

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(5) Plot the computed values as shown in figure 16 and manipulate the resulting *P* and *H* curves according to the symbolic formula:

$$H - P = H_2 + H = d_2 - P = H_3 \dots H_n + H = d_n$$

Since the program (as given by Bissiri and Landau) does not state the location of the nearest dead end, the dead end will be assumed, first, a great distance away and, second, at insulator No. 1 in span E.

(6) For the dead end a great distance away, the solution is given by the symbolic formula:

$$\enclose{circle}{d_n} \times P \downarrow H_n \rightarrow \enclose{circle}{d_n} \downarrow H_n \rightarrow \enclose{circle}{d_n} \dots H_0$$

For the dead end at insulator No. 1, the solution is given by the symbolic formula:

$$\enclose{circle}{d_6} \times P \downarrow H_6 \rightarrow \enclose{circle}{d_5} \downarrow H_5 \rightarrow \enclose{circle}{d_4} \downarrow H_4 \rightarrow \enclose{circle}{d_3} \downarrow H_3 \rightarrow \enclose{circle}{d_2}$$

The results are tabulated in table E.

By the more exact method, the procedure is as follows:

(1) Compute an *H* curve for each span. Assume that span E is dead ended at insulator No. 1 and that all spans are level spans without correction since the correction is less than 2 feet for each span. These values are given in table C.

(2) Compute a *P* curve for each suspension insulator string. These values are given in table D.

(3) Plot the *H* and *P* curves as shown in figure 17 and manipulate them graphically according to the symbolic formula:

$$H_E - P_2 + H_E' + H_D = d_3 - P_3 = H_D' + H_C = d_4 - P_4 = H_C' + H_B = d_5 - P_5 = H_B' + H_A = d_6 - P_6 = H_A'$$

(4) The solution is given by the following symbolic formula:

$$\enclose{circle}{d_6} \times P_6 \downarrow H_B' \rightarrow \enclose{circle}{d_5} \downarrow H_C' \rightarrow \enclose{circle}{d_4} \downarrow H_D' \rightarrow \enclose{circle}{d_3} \downarrow H_E' \rightarrow \enclose{circle}{d_2}$$

The results are tabulated in table E.

Discussion of Results.–Considering the inherent differences between the methods used to solve the typical problem, the results check each other as well as could be expected. The principal difference between the methods lies in the assumption made by Bissiri and Landau that the conductor length in the span adjacent to a break is increased by the length of the insulator string immediately adjacent to the break. Theoretically, this would be true only if the weight distribution over the insulator string were the same as that over the conductor, and if no concentrated loads such as holddown weights, armor rods, vibration dampers, etc., were acting. Since the unit weight of an insulator string is usually several times that of a conductor, the effects of such a discontinuity of weight distribution depend on the relative magnitudes of the tension in the system to the total weight of conductor, insulators, and concentrated loads comprising the system. Hence, the assumption made by Bissiri and Landau has a varying effect, being more correct for long spans with high tensions than for short spans with low tensions.

V–APPENDIX A-2

To facilitate certain computations such as made in Appendix A-1, a Ruling Span Computation Chart and a Sag and Tension Computation Chart have been devised. These are self-explanatory and are given on the following pages as figures 18 and 19, respectively.

Figure 20 shows a typical set of data by which preliminary studies of the effects of a broken conductor can be facilitated. The span-tension curves have been plotted from data computed for several specific ruling span lengths by the approximate method as presented herein.

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Table A.–*H curve computation*

$$\phi = L_0 - \frac{2H_1}{w}\sinh^{-1}\left[\frac{\left(H_0 \sinh\frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1}\right]$$

$H_0 = 4400$ lb; $L_0 = 970$ ft; $w = 1.57$ lb/ft; $AE = 6{,}635{,}672$

1	2	3	4	5	6	7	8	9
H_1	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$ (5)	$\frac{2H_1}{w}$	(6) (7)	$L_0 -$ (8)
2300	765.2528	0.999638	765.0106	0.33261	0.3268	2929.936	957.503	12.5
2500	765.2528	.999713	765.0331	.30601	.3015	3184.713	959.880	10.12
3000	765.2528	.999789	765.0913	.25500	.2524	3821.650	964.584	5.42
4000	765.2528	.999939	765.2066	.19130	.1902	5095.540	969.171	0.83

Numbers in parenthesis are column numbers.

Table B.–*P curve computation*

$$P = \frac{Wd}{l \cos\theta}$$

$W = 1655$ lb; $l = 12.58$ ft $= 150.96$ in

d	$\frac{d}{l}$	$\cos\theta$	$\frac{d}{l\cos\theta}$	P
30	0.1987	0.4803	0.2027	335.5
60	.3975	.9178	.4331	716.8
90	.5962	.8028	.7426	1229.0
120	.7949	.6074	1.3086	2165.7
130	.8611	.5090	1.6910	2798.6

Table C.–*H curve computations*

$$\phi = L_0 - \frac{2H_1}{w} \sinh^{-1} \left[\frac{\left(H_0 \sinh \frac{wL_0}{2H_0}\right)\left(1 \pm \frac{H_0 - H_1}{AE}\right)}{H_1} \right]$$

$H_0 = 4400$ lb; $w = 1.57$ lb/ft; $AE = 6{,}635{,}672$
$L_0 = 880, 910, 980,$ and 1050 ft

	1	2	3	4	5	6	7	8	9
Span	H_1	$H_0 \sinh \frac{wL_0}{2H_0}$	$1 - \frac{H_0 - H_1}{AE}$	(2) (3)	$\frac{(4)}{H_1}$	$\sinh^{-1}$ (5)	$\frac{2H_1}{w}$	(6) (7)	L_0 − (8)
880	2200	693.6416	0.999668	693.4116	0.3152	0.3102	2802.548	869.350	10.6
	2500	693.6416	.999714	693.4429	.2774	.2739	3184.710	872.292	7.7
	3000	693.6416	.999789	693.4951	.2309	.2289	3821.660	874.777	5.2
	4000	693.6416	.999939	693.5996	.1734	.1725	5095.540	878.981	1.02
910	2200	717.4822	.999668	717.2443	.3260	.3205	2802.548	898.216	11.8
	2500	717.4822	.999714	717.2768	.2869	.2831	3184.710	901.591	8.4
	3000	717.4822	.999789	717.3308	.2389	.2366	3821.660	904.205	5.8
	4000	717.4822	.999939	717.4384	.1794	.1783	5095.540	908.980	1.02
980	2300	773.2210	.999683	772.9763	.3361	.3300	2929.936	996.879	13.12
	2500	773.2210	.999714	772.9996	.3092	.3044	3184.710	969.426	10.6
	3000	773.2210	.999789	773.0579	.2574	.2547	3821.660	973.377	6.62
	4000	773.2210	.999939	773.1744	.1933	.1921	5095.540	978.853	1.15
1050	2500	829.0365	.999714	828.7991	.3315	.3258	3184.710	1037.597	12.4
	3000	829.0365	.999789	828.8616	.2760	.2727	3821.660	1042.166	7.83
	4000	829.0365	.999939	828.9865	.2072	.2058	5095.540	1048.662	1.34

Numbers in parenthesis are column numbers.

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Table D.–*P Curve computations*

$$P = \frac{Wd}{i \cos \theta}$$

i = 12.58 ft = 150.96 in

d	$\frac{d}{i}$	$\cos \theta$	$\frac{d}{i \cos \theta}$	P_2 $W = 1750$	P_3 $W = 1546$	P_4 $W = 1609$	P_5 $W = 1766$	P_6 $W = 730$
30	0.1987	0.9803	0.2027	354.7	313.4	326.1	357.9	174.9
60	.3975	.9178	0.4331	757.9	669.6	696.9	764.9	316.2
90	.5962	.8028	0.7426	1299.6	1148.1	1194.8	1311.4	542.1
120	.7949	.6074	1.3086	2290.1	2023.1	2105.5	2310.9	955.3
130	.8611	.5090	1.6910	2959.3	2614.3	2720.2	2986.3	1234.4
140	.9274	.3740	2.4790					1809.7
142	.9406	.3394	2.7710					2022.8
144	.9539	.3002	3.1770					2319.2
146	.9671	.2542	3.8050					2777.6

Table E.–*Tabulation of results*

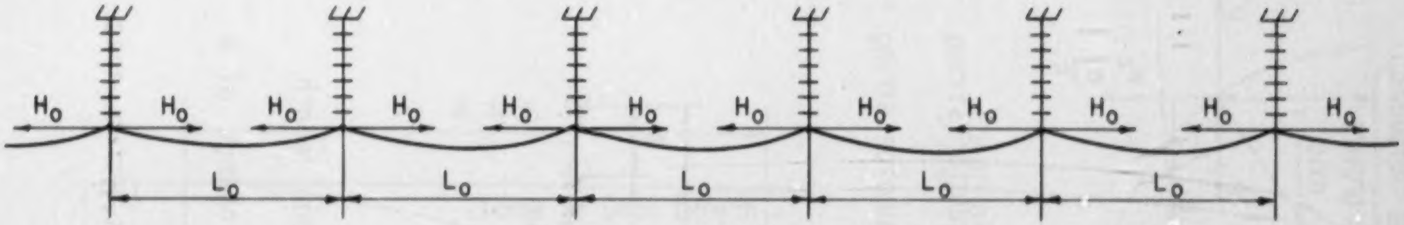
Item	Approximate method		Exact method	Bissiri and Landau [1]
	Dead end a great dist. from break	Dead end at insulator No. 1		
Tension (lb)–A	2920	2900	2710	2625
–B	3590	3550	3620	
–C	3930	3870	3950	
–D	4120	4050	4120	
–E	4230	4120	4220	
Insulator deflection (in)–6	131.2	131.1	145.8	
–5	58.0	57.8	67.4	
–4	31.2	30.0	32.8	
–3	18.0	16.0	17.0	
–2	10.8	6.9	7.5	
[2] Sag (ft)–A	53.0	53.5	57.0	59.0

---

[1] For a final result, Bissiri and Landau give only an interpolated catenary parameter value for the span adjacent to the break. From this, Tension A = (1670)(1.57) = 2625 lb.

[2] Sag values determined by use of Computing Chart given in figure 19.

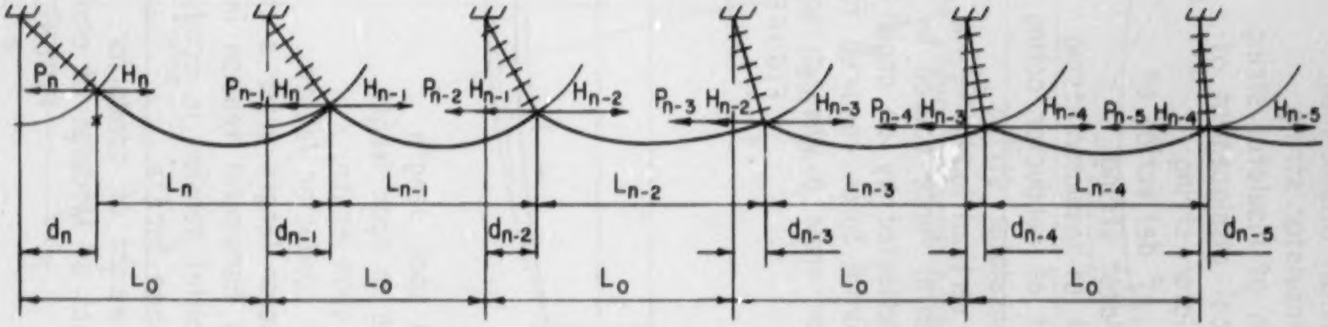
INITIAL CONDITIONS - Before Break



H_o = Horizontal tension in conductor
L_o = Span length

FIGURE 1

FINAL CONDITIONS - After Break



P_n
H_n
P_{n-1}
H_{n-1}
P_{n-2}
H_{n-2}
P_{n-3}
H_{n-3}
P_{n-4}
H_{n-4}
P_{n-5}
H_{n-5}
L_n
L_{n-1}
L_{n-2}
L_{n-3}
L_{n-4}
d_n
d_{n-1}
d_{n-2}
d_{n-3}
d_{n-4}
d_{n-5}
L_o

Conditions for equilibrium: $\emptyset$ = Change in span length.

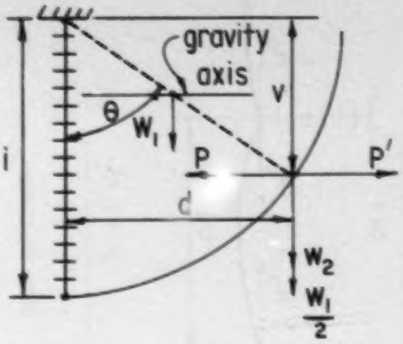
$P_n = H_n$; $P_{n-1} + H_n = H_{n-1}$; $P_{n-2} + H_{n-1} = H_{n-2}$; $P_{n-3} + H_{n-2} = H_{n-3}$; etc.

$\emptyset_n = d_n - d_{n-1}$; $\emptyset_{n-1} = d_{n-1} - d_{n-2}$; $\emptyset_{n-2} = d_{n-2} - d_{n-3}$; $\emptyset_{n-3} = d_{n-3} - d_{n-4}$; etc.

$L_n = L_o - \emptyset_n$; $L_{n-1} = L_o - \emptyset_{n-1}$; $L_{n-2} = L_o - \emptyset_{n-2}$, $L_{n-3} = L_o - \emptyset_{n-3}$; etc.

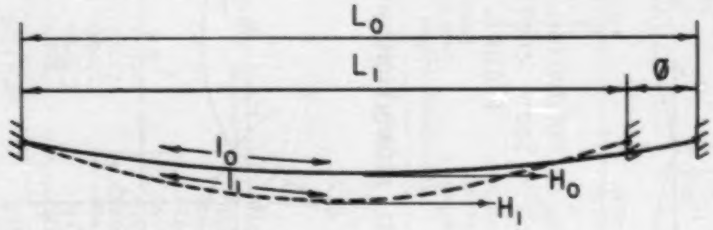
FIGURE 2

104-D-1121



d - Horizontal displacement of insulator string.
i - Length of insulator string.
v - Vertical displacement of insulator string.
θ - Angle of deflection of insulator string.
w_1 - Weight of insulator string.
w_2 - Weight of conductor acting on insulator string.
W - Total vertical load $= \frac{w_1}{2} + w_2$.
P - Horizontal force caused by W when the insulator string is deflected by an angle θ.
P′ - Horizontal force required to deflect the insulator string by an angle θ when a load W is acting.

FIGURE 3



L_0 - Initial span length.
Ø - Change in span length.
L_1 - Final span length.
l_0 - Initial conductor length.
l_1 - Conductor length after a change of Ø in span length.
H_0 - Initial horizontal tension in conductor.
H_1 - Horizontal tension in conductor after a change of Ø in span length.
w - Unit weight of conductor.
AE - Product of Modulus of elasticity and cross section area.

FIGURE 4

104-D-1122

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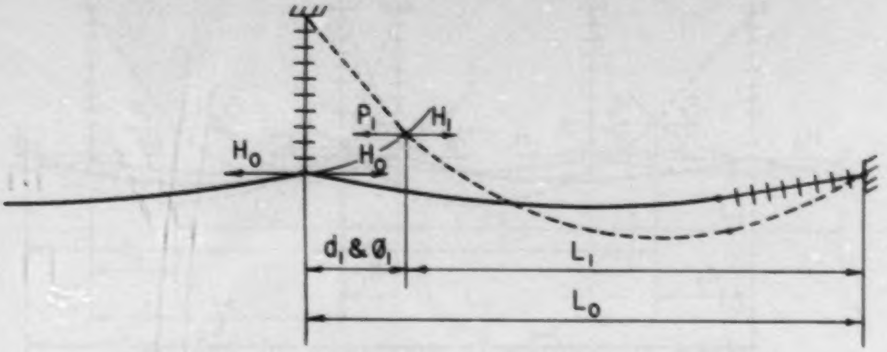
Conductor Break in a Span Adjacent to a Dead End



Conditions for equilibrium after conductor breaks:
$P_1 = H_1$; $Ø_1 = d_1$; $L_1 = L_0 - Ø_1$

FIGURE 5

P & H Force Relations

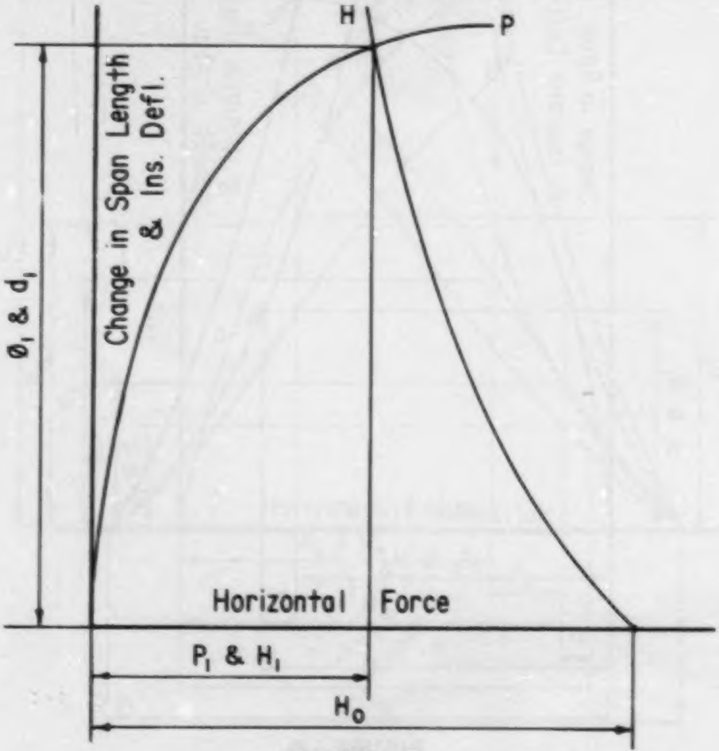
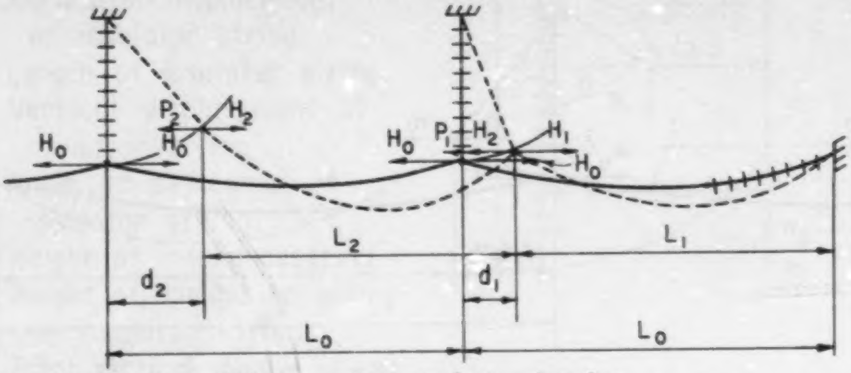


FIGURE 6

104-D-1123

Conductor Break Two Spans Removed From Dead End


H₀
P₂
H₂
H₀
H₀
P₁
H₂
H₁
H₀
L₂
L₁
d₂
d₁
L₀
L₀

Conditions for equilibrium after conductor breaks:
$P_2 = H_2$; $P_1 + H_2 = H_1$; $\emptyset_2 = d_2 - d_1$; $\emptyset_1 = d_1$; $L_2 = L_o - \emptyset_2$; $L_1 = L_o - \emptyset_1$

FIGURE 7

P & H Force Relations

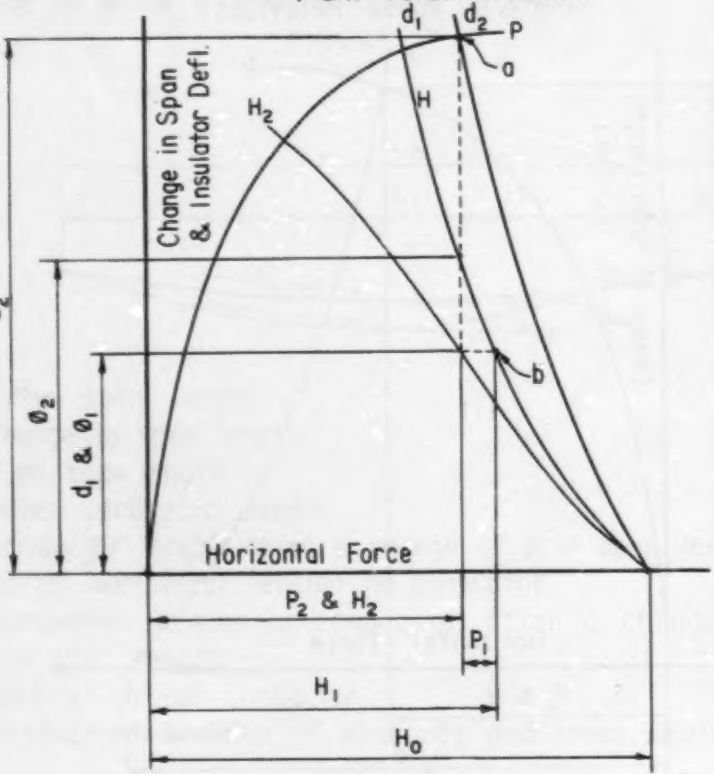

d₁
d₂
P
a
H₂
H
Change in Span & Insulator Defl.
d₂
Ø₂
d₁ & Ø₁
b
Horizontal Force
P₂ & H₂
P₁
H₁
H₀

FIGURE 8

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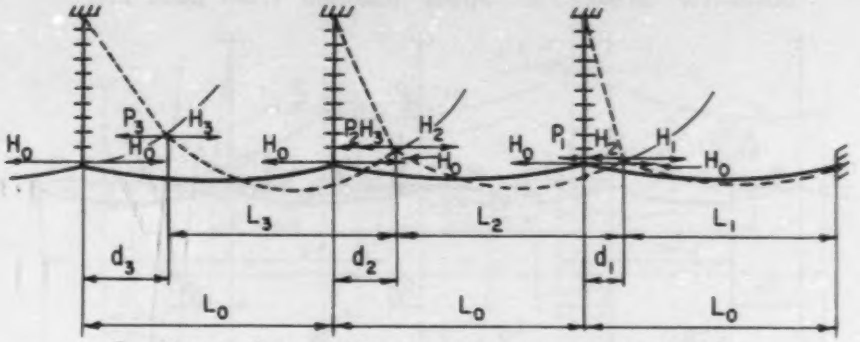
Conductor Break Three Spans Removed From Dead End


H0
P3
H3
H0
H0
P2 H3
H2
H0
H0
P1
H2
H1
H0
L3
L2
L1
d3
d2
d1
L0
L0
L0

Conditions for equilibrium after conductor breaks:

$P_3 = H_3$; $P_2 + H_3 = H_2$; $P_1 + H_2 = H_1$; $\emptyset_3 = d_3 - d_2$; $\emptyset_2 = d_2 - d_1$;
$\emptyset_1 = d_1$; $L_3 = L_0 - \emptyset_3$; $L_2 = L_0 - \emptyset_2$; $L_1 = L_0 - \emptyset_1$

FIGURE 9

P & H Force Relations

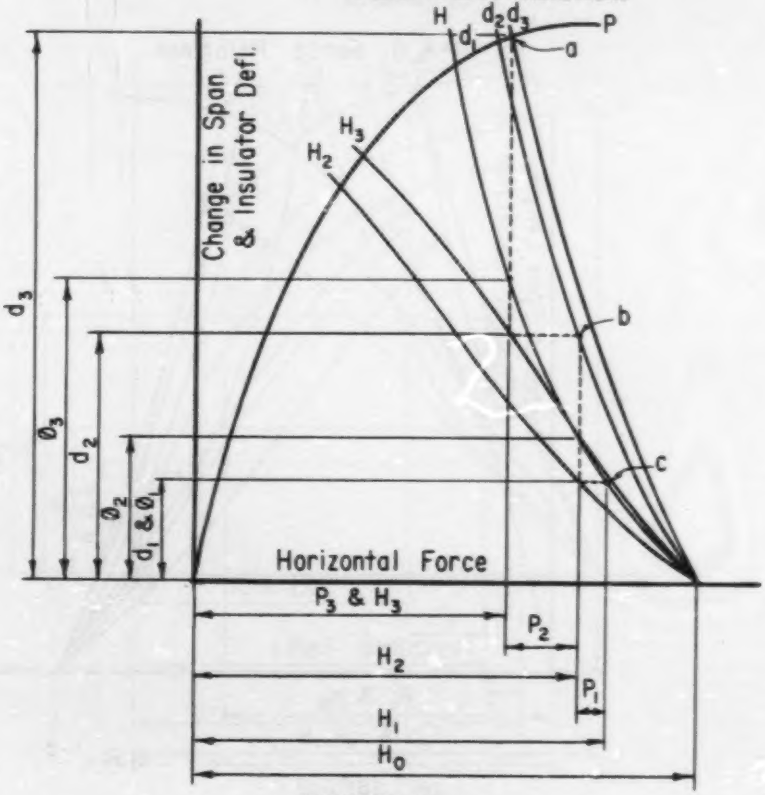
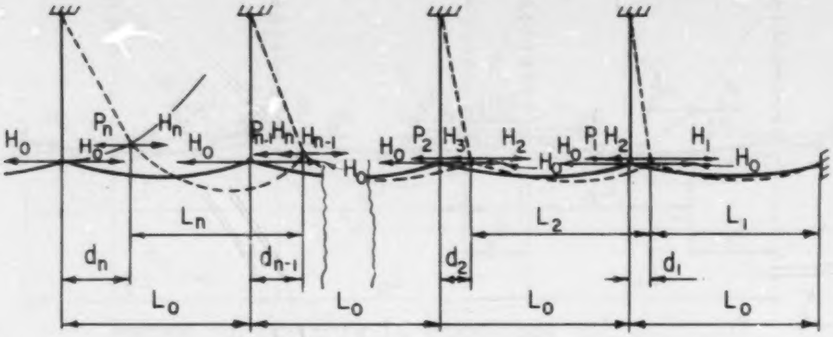

H
d2
d3
P
d1
a
H3
H2
Change in Span & Insulator Defl.
b
c
d3
Ø3
d2
Ø2
d1 & Ø1
Horizontal Force
P3 & H3
P2
H2
P1
H1
H0

FIGURE 10

104-D-1125

Conductor Break "n" Spans Removed from Dead End


H_o
P_n
H_n
H_o
H_o
P_{n-1}
H_n
H_{n-1}
H_o
P_2
H_3
H_2
H_o
P_1
H_2
H_1
H_o
H_o
L_n
L_2
L_1
d_n
d_{n-1}
d_2
d_1
L_o
L_o
L_o
L_o

Conditions for equilibrium after conductor breaks:

$P_n = H_n$; $P_{n-1} + H_n = H_{n-1}$; --- $P_1 + H_2 = H_1$ $\varnothing_n = d_n - d_{n-1}$; $\varnothing_{n-1} = d_{n-1} - d_{n-2}$; --- $\varnothing_1 = d_1$

$L_n = L_o - \varnothing_n$; $L_{n-1} = L_o - \varnothing_{n-1}$; --- $L_1 = L_o - \varnothing_1$

FIGURE 11

P & H Force Relations

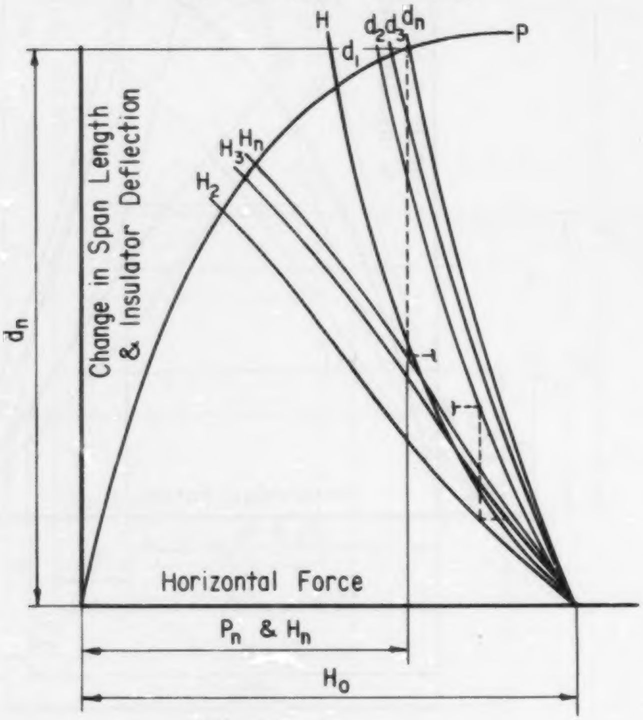


FIGURE 12

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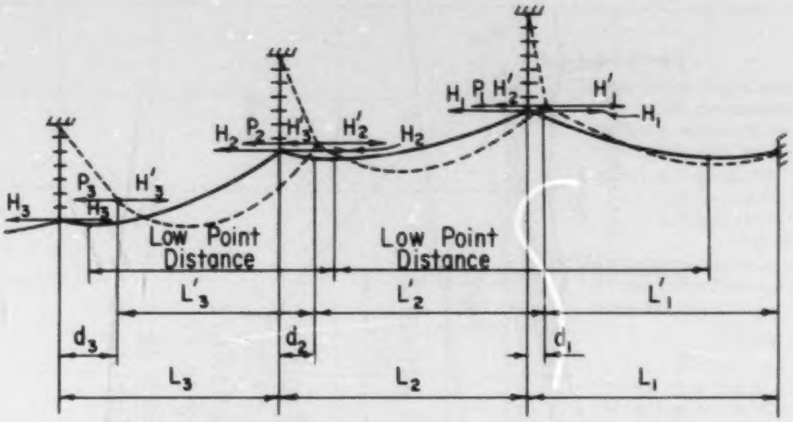
H_3
P_3
H'_3
H_3
H_2
P_2
H'_3
H'_2
H_2
H_1
P_1
H'_2
H'_1
H_1
Low Point Distance
Low Point Distance
L'_3
L'_2
L'_1
d_3
d_2
d_1
L_3
L_2
L_1

Conditions for equilibrium after conductor breaks:
$P_3 = H'_3$; $P_2 + H'_3 = H'_2$; $P_1 + H'_2 = H'_1$; $\emptyset_3 = d_3 - d_2$; $\emptyset_2 = d_2 - d_1$;
$\emptyset_1 = d_1$; $L'_3 = L_3 - \emptyset_3$; $L'_2 = L_2 - \emptyset_2$; $L'_1 = L_1 - \emptyset_1$

FIGURE 13

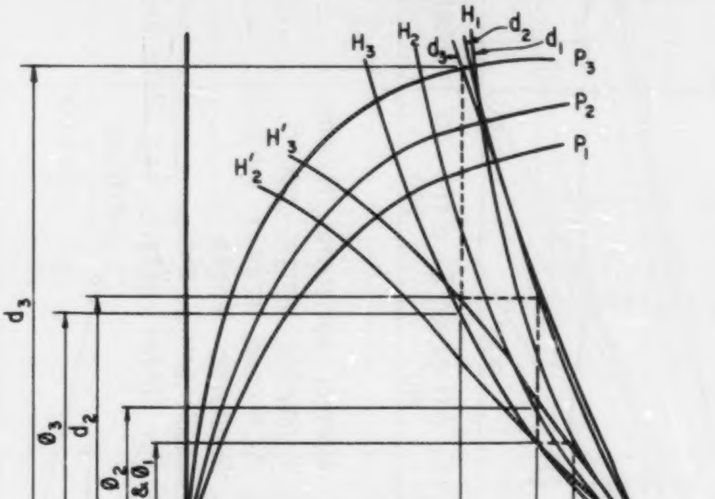
H_1
H_3
H_2
d_2
d_1
d_3
P_3
P_2
P_1
H'_3
H'_2
d_3
$\emptyset_3$
d_2
$\emptyset_2$
d_1 & $\emptyset_1$
P_3 & H'_3
P_2
H'_2
P_1
H'_1
H_1, H_2, & H_3

FIGURE 14

104-D-1127

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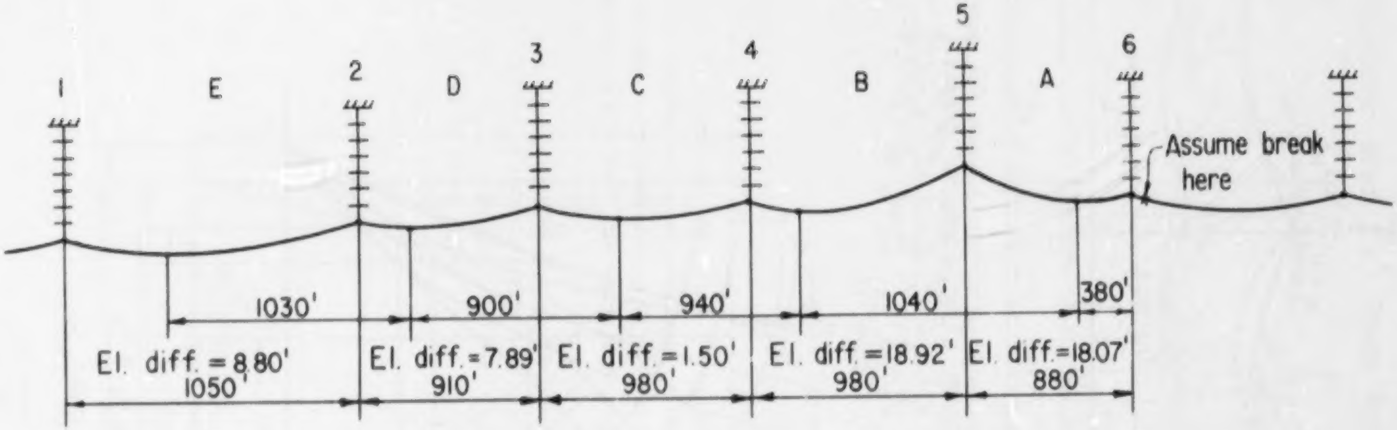
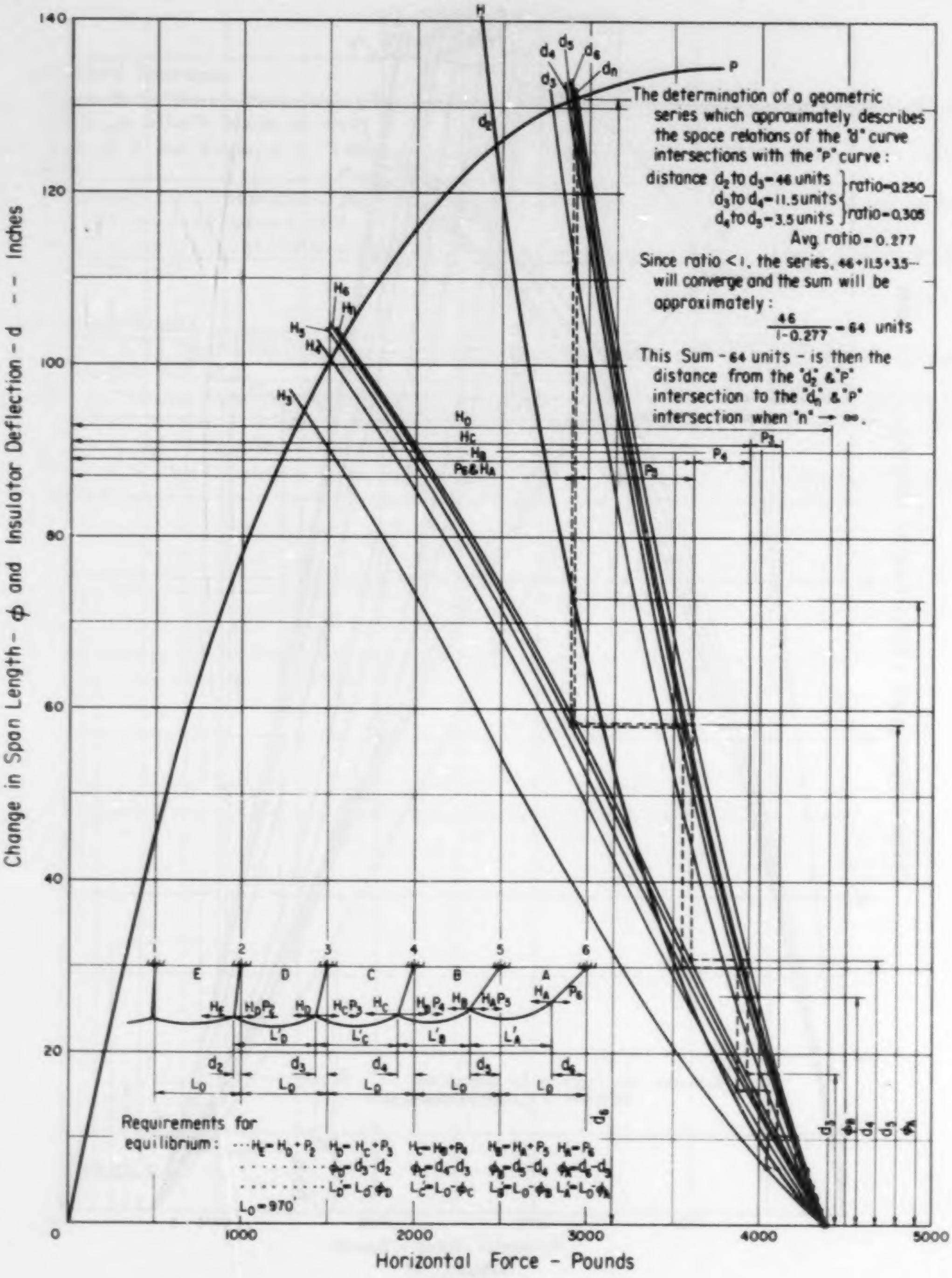

1
E
2
D
3
C
4
B
5
A
6
Assume break here
1030'
900'
940'
1040'
380'
El. diff. = 8.80'
1050'
El. diff. = 7.89'
910'
El. diff. = 1.50'
980'
El. diff. = 18.92'
980'
El. diff. = 18.07'
880'

Normal horizontal tension ---------- H_o = 4400 lb
Conductor weight per ft ---------- w = 1.57 lb
AE = cond. area x modulus ---------- = 6,635,672
Insulator length ---------- i = 12.58 ft
Insulator weight ---------- = 265 lb
For other details see Reference [4] - Bibliography

FIGURE 15

104-D-1128



The determination of a geometric series which approximately describes the space relations of the "d" curve intersections with the "P" curve:

distance d_2 to d_3 = 46 units
d_3 to d_4 = 11.5 units
d_4 to d_5 = 3.5 units
ratio = 0.250
ratio = 0.305
Avg. ratio = 0.277

Since ratio < 1, the series, 46 + 11.5 + 3.5 --- will converge and the sum will be approximately:

$$\frac{46}{1-0.277} = 64 \text{ units}$$

This Sum - 64 units - is then the distance from the "d_2" & "P" intersection to the "d_n" & "P" intersection when "n" → ∞.

Requirements for equilibrium:
$H_E = H_D + P_2$ $H_D = H_C + P_3$ $H_C = H_B + P_4$ $H_B = H_A + P_5$ $H_A = P_6$
$\phi_D = d_3 - d_2$ $\phi_C = d_4 - d_3$ $\phi_B = d_5 - d_4$ $\phi_A = d_6 - d_5$
$L'_D = L_0 - \phi_D$ $L'_C = L_0 - \phi_C$ $L'_B = L_0 - \phi_B$ $L'_A = L_0 - \phi_A$
$L_0 = 970'$

FIGURE 16

104-D-1129

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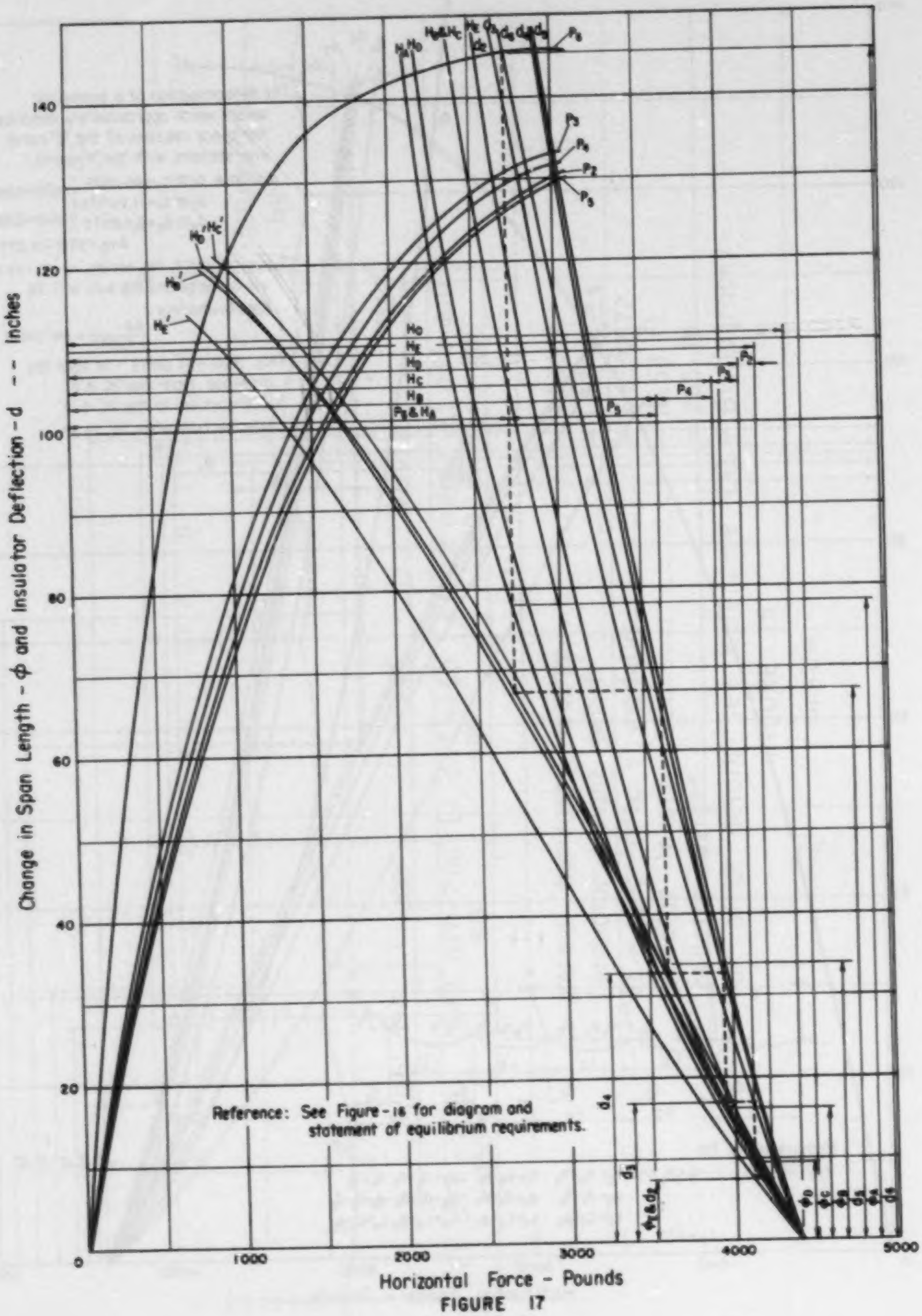

FIGURE 17

104-D-1130

VI–BIBLIOGRAPHY

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[2] Healy, E. S., and Wright, A. J., "Unbalanced Conductor Tensions," Trans. of AIEE, pp. 1064-1070, September, 1926.

[3] Den Hartog, J. P., "Calculation of Sags in a Transmission Line With a Broken Conductor," The Electric Journal, vol. XXV, pp. 24-26, January, 1928.

[4] Bissiri, A., and Landau, M., "Broken Conductor Effect on Sags in Suspension Spans," Trans. of AIEE, vol, 66, pp. 1181-1188, 1947.

Technical Books

[5] Painton, E. T., "Mechanical Design of Overhead Electrical Transmission Lines," D. Van Nostrand Co., New York, pp. 265-269, 1925.

[6] Still, A., "Electric Power Transmission," Third Edition, McGraw-Hill Book Co., New York, pp. 137-138, 1927.

[7] Pender, H., Del Mar, W. A., and McIlwain, K., "Electrical Engineers Handbook–Electric Power," Third Edition, Section 14, pp. 71-73, 1936.

[8] Martin, J. S., "Sag Calculations by the Use of Martin's Tables," Copperweld Steel Co., Glassport, Pa., pp. 39-40, 1942.

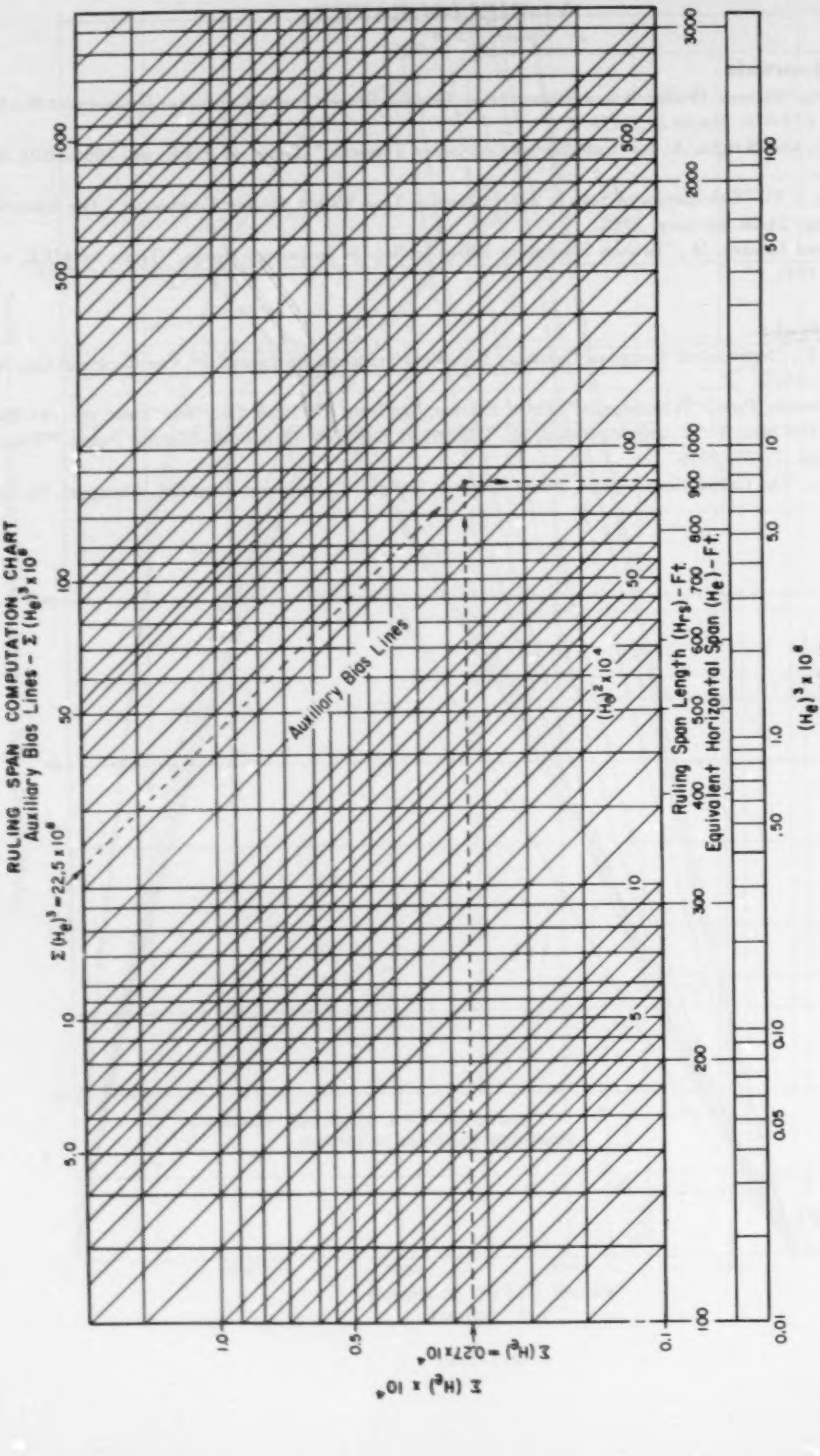
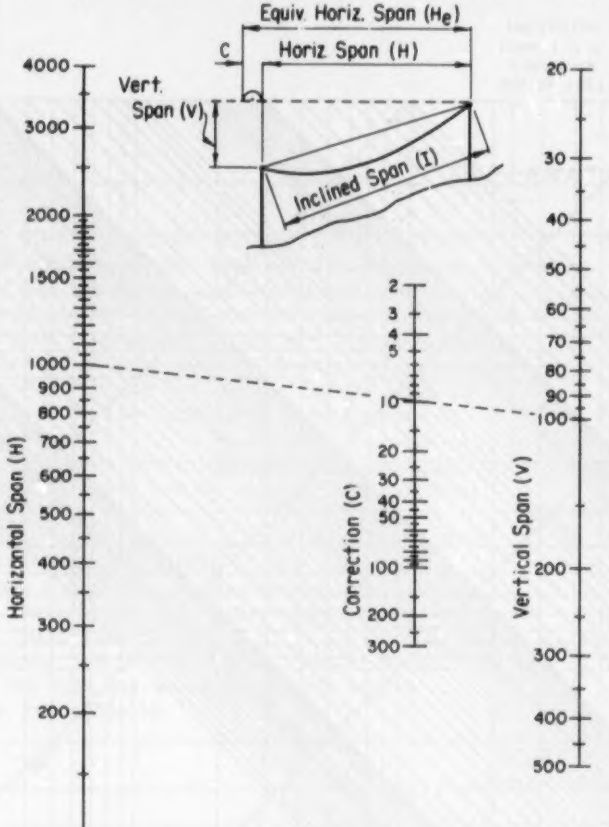


FIGURE 18
(Sheet 1 of 2)

104-D-1131

EQUIVALENT HORIZONTAL SPAN NOMOGRAPH


Equiv. Horiz. Span (H_e)
C
Horiz. Span (H)
Vert. Span (V)
Inclined Span (I)
Horizontal Span (H)
4000
3000
2000
1500
1000
900
800
700
600
500
400
300
200
100
Correction (C)
2
3
4
5
10
20
30
40
50
100
200
300
Vertical Span (V)
20
30
40
50
60
70
80
90
100
200
300
400
500

EXAMPLE: Horizontal span (H) = 1000'
Vertical span (V) = 100'
Correction (C) = 10'
Equiv. horiz. span = 1010'

NOTES

These charts are designed to facilitate the computation of the ruling span length for any series of suspension spans.

The procedure for computing the ruling span length is as follows:

1. Compute the Equivalent Horizontal Span (H_e) for each span in the series being considered by using the nomograph which is based on J.S. Martin's formula: $H_e = 2I - H$. (Use only for spans of 20% slope or less.)
2. The Ruling Span Length is then computed by using the relation: $H_{rs} = \sqrt{\Sigma H_e^3 / \Sigma H_e}$, the solution of which is facilitated by using the Ruling Span Computation Chart.

EXAMPLE

Problem: Find the ruling span length for a series of level spans of lengths, $H_e = 800$, 900, & 1000 ft.

Solution: (Using the Ruling Span Chart).

1. Enter the equivalent horizontal scale at the span lengths given and read the corresponding H_e^3 values.
2. Add the H_e^3 & H_e values:
   $\Sigma H_e = 2700$: $\Sigma H_e^3 = 22.5 \times 10^8$
3. Enter the auxiliary bias lines at the value corresponding to $\Sigma H_e^3 = 22.5 \times 10^8$ and read down the bias line to the intersection of the horizontal $\Sigma H_e = 0.27 \times 10^4$ line.
4. Project vertically down from this point to the H_{rs} scale and read the ruling span length of 910 ft.

FIGURE 18
(Sheet 2 of 2)

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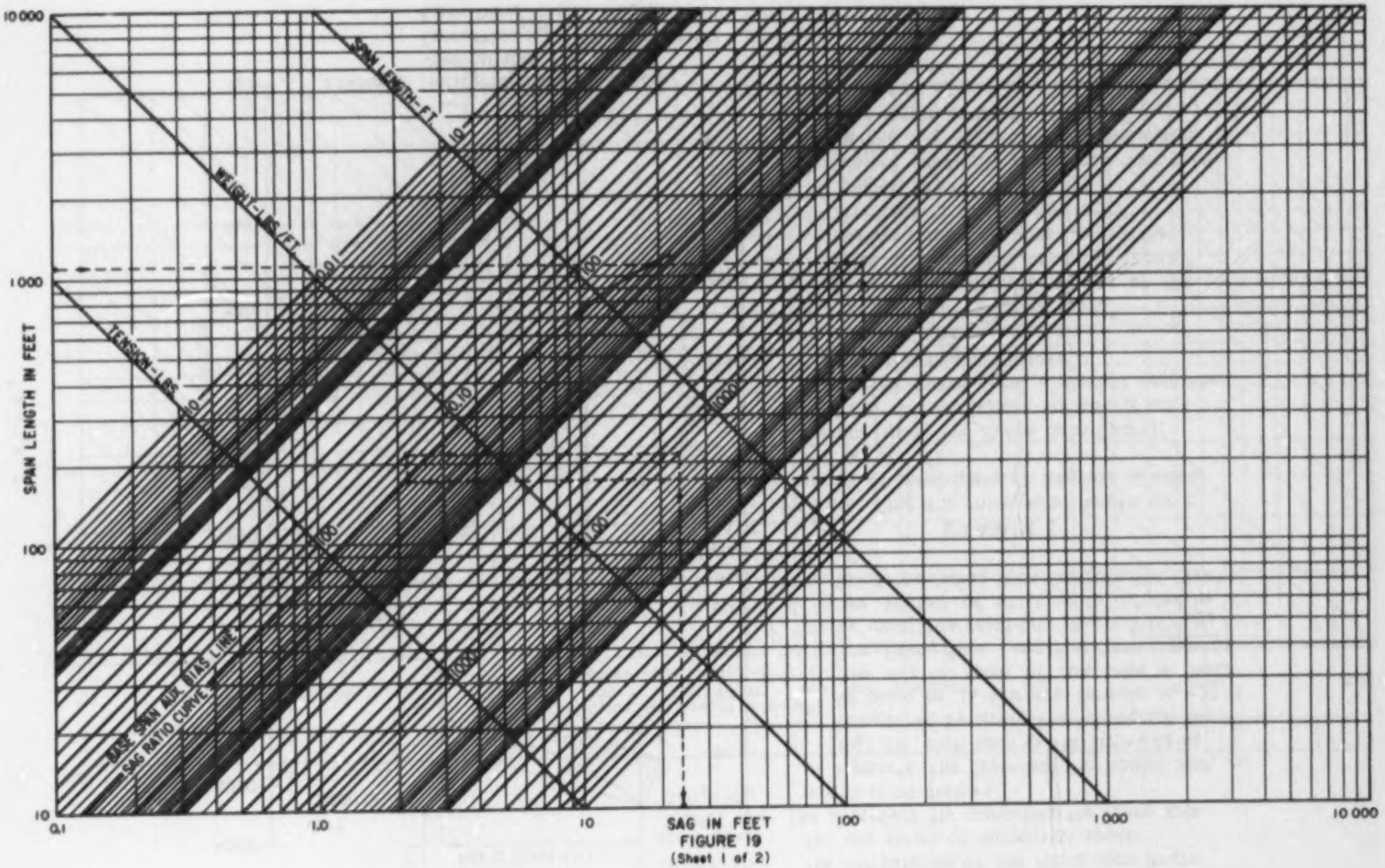


FIGURE 19
(Sheet 1 of 2)
104-D-1132

EXPLANATION

The purpose of this chart is to facilitate the computation of transmission line conductor sags and tensions when any three of the elements - span length, unit weight, sag, or tension are known and when accuracy beyond the first decimal place is not required. This chart is based on the catenary functions as derived by J.S. Martin and given in the pamphlet "Sag Calculations By The Use Of Martin's Tables" published by the Copperweld Steel Company, Glassport, Pa.

The procedure for computing a sag value when the span length, unit weight, and tension are known is as follows:

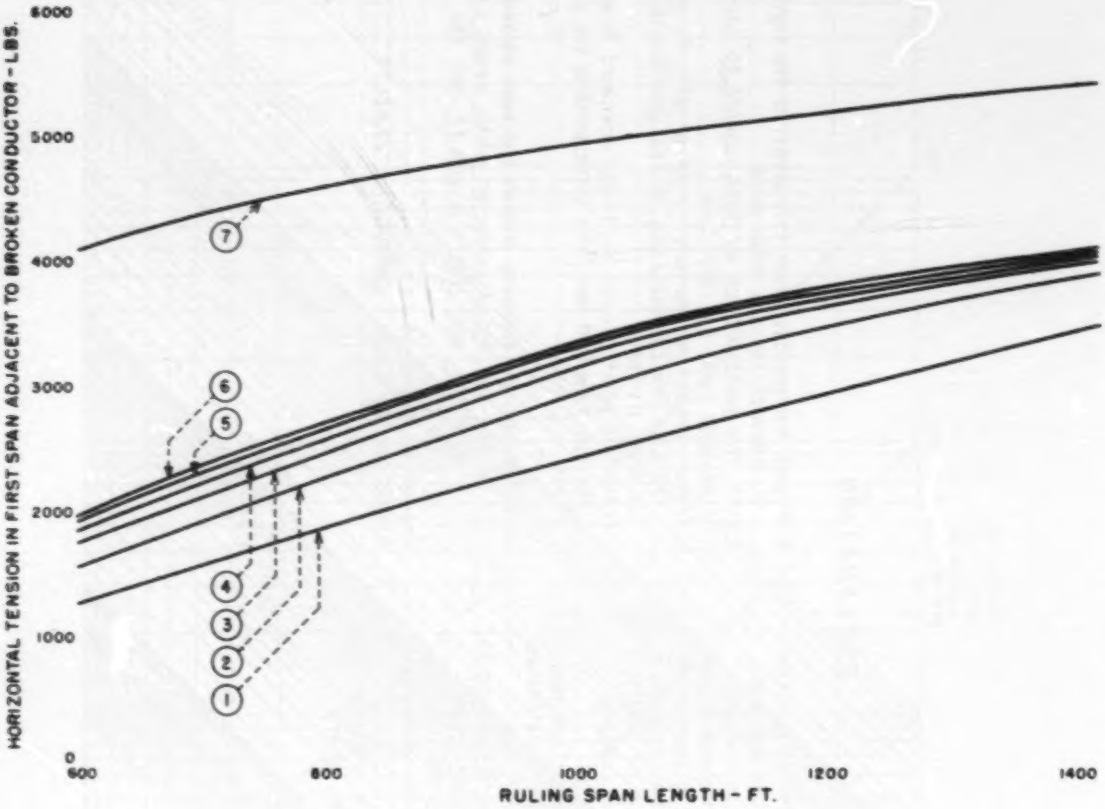
1. Enter the span length scale at a point corresponding to the equivalent level span length of the span under consideration and project horizontally to the right to intersect the bias line which corresponds to the unit weight of the conductor.
2. Project vertically -up or down- from this point to intersect the bias line which corresponds to the tension in the conductor.
3. Project horizontally from this point to the right or left to intersect the sag ratio curve.
4. From this point project vertically upward to intersect the Base Span Aux. Bias Line.
5. Thence, project horizontally -right or left- to intersect the bias line corresponding to the span length used in step (1) above.
6. From this point project vertically downward to intersect the sag scale and read the corresponding sag value in feet.

As an example, the following problem has been worked through: Find the sag for a conductor which weighs 1.1 lb. per ft. when the span length is 1100 ft. and the tension is 7000 lb.

Answer by chart: 23.9 ft.

Answer by more exact computation: 23.871 ft.

FIGURE 19
(Sheet 2 of 2)



1. Dead-end in first span adjacent to break.
2. Dead-end in second span adjacent to break.
3. Dead-end in third span adjacent to break.
4. Dead-end in fourth span adjacent to break.
5. Dead-end in fifth span adjacent to break.
6. Dead-end a great distance from break.
7. Tension before break.

FIGURE 20
(Sheet 1 of 2)
104-D-1133

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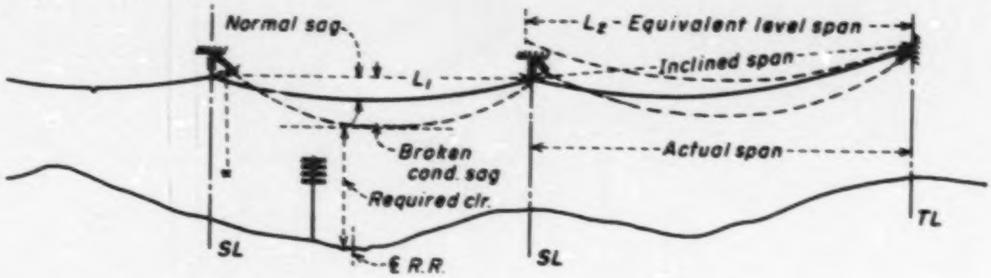
NOTES

These curves are to be used in making preliminary determinations of conductor heights at crossings which warrant compliance with National and/or Local safety codes and are based on the following:

Conductor – 795,000 C.M. A.C.S.R. 26/7 stranding.
Loading – 130°F. final no load with max. load = 7500 lbs. @ 25°F. and 8# wind.
Insulators – 16, 5¾" x 10" suspension units.

The following example is given to illustrate the use of the curves shown to the left.

PROBLEM: Determine conductor heights at crossing shown below, making provisions for required clearance under broken conductor conditions.



PROCEDURE:

FIRST – From pertinent safety codes determine required clearance over crossing.

SECOND – Determine the ruling span from crossing span to nearest dead-end by:

$$RS = \sqrt{\frac{L_1^3 + L_2^3 \cdots}{L_1 + L_2 \cdots}}$$

Note: L_1, L_2, etc. are equivalent level spans, where the equivalent level span = 2 (Inclined span) – actual span.

THIRD – Enter the curves at the value of the ruling span as determined above and using the curve which best describes the location of the nearest dead-end read the corresponding value of horizontal tension. For dead-ends more than 5 spans from break use curve No. 6.

FOURTH – Determine broken conductor sag and/or profile as required.

$$\text{Broken cond. sag} = \frac{H}{1.098}\left[\cosh\left(\frac{0.549\,L_1}{H}\right) - 1\right];$$

H = Tension read from pertinent curve.

In applying conductor profile to transmission line profile, the shift in the span due to the conductor break need be considered only for very short spans.

FIFTH – For a level crossing span, conductor height = required clr. + broken cond. sag. For an inclined span, use height as indicated by intercepts of the broken cond. profile on the structure center lines.

FIGURE 20
(Sheet 2 of 2)

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« Appendix B

USEFUL FIGURES AND TABLES

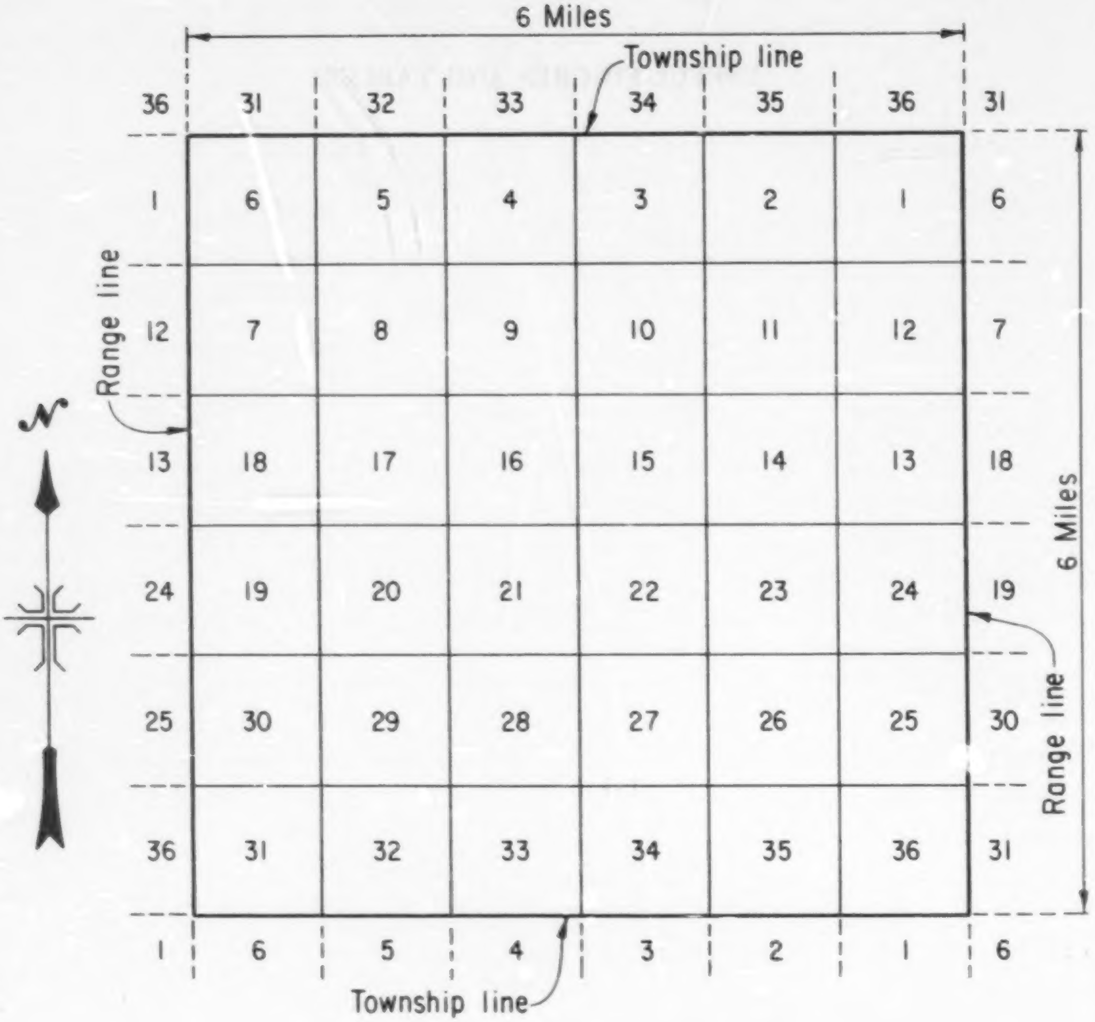
6 Miles
Township line
36
31
32
33
34
35
36
31
1
6
5
4
3
2
1
6
Range line
12
7
8
9
10
11
12
7
N
13
18
17
16
15
14
13
18
6 Miles
24
19
20
21
22
23
24
19
25
30
29
28
27
26
25
30
Range line
36
31
32
33
34
35
36
31
1
6
5
4
3
2
1
6
Township line

Figure B-1.–Typical township showing section numbering. 104-D-1134.

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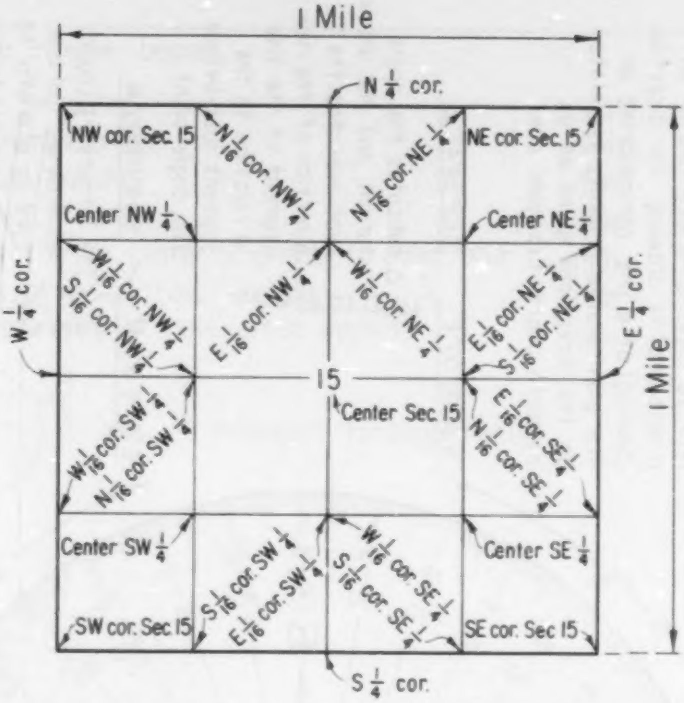
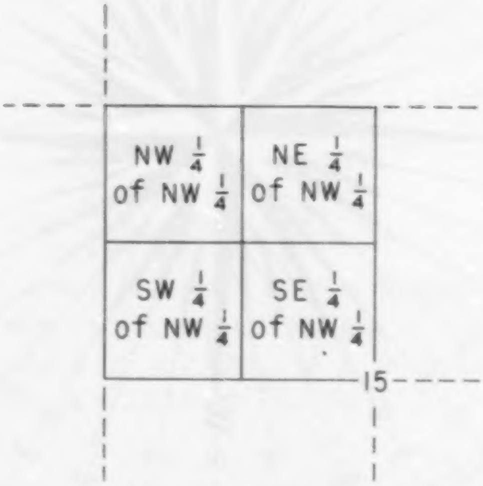

1 Mile
N 1/4 cor.
NW cor. Sec. 15
N 1/16 cor. NW 1/4
N 1/16 cor. NE 1/4
NE cor. Sec. 15
Center NW 1/4
Center NE 1/4
W 1/4 cor.
W 1/16 cor. NW 1/4
S 1/16 cor. NW 1/4
E 1/16 cor. NW 1/4
W 1/16 cor. NE 1/4
E 1/16 cor. NE 1/4
S 1/16 cor. NE 1/4
E 1/4 cor.
1 Mile
15
Center Sec. 15
W 1/16 cor. SW 1/4
N 1/16 cor. SW 1/4
E 1/16 cor. SE 1/4
N 1/16 cor. SE 1/4
Center SW 1/4
Center SE 1/4
S 1/16 cor. SW 1/4
E 1/16 cor. SW 1/4
W 1/16 cor. SE 1/4
S 1/16 cor. SE 1/4
SW cor. Sec. 15
SE cor. Sec. 15
S 1/4 cor.

Typical Section of Land Showing Corner Designations


NW 1/4 of NW 1/4
NE 1/4 of NW 1/4
SW 1/4 of NW 1/4
SE 1/4 of NW 1/4
15

Typical 1/4 Section

Figure B-2.–Typical land section showing corner and 1/16 designations. 104-D-1135.

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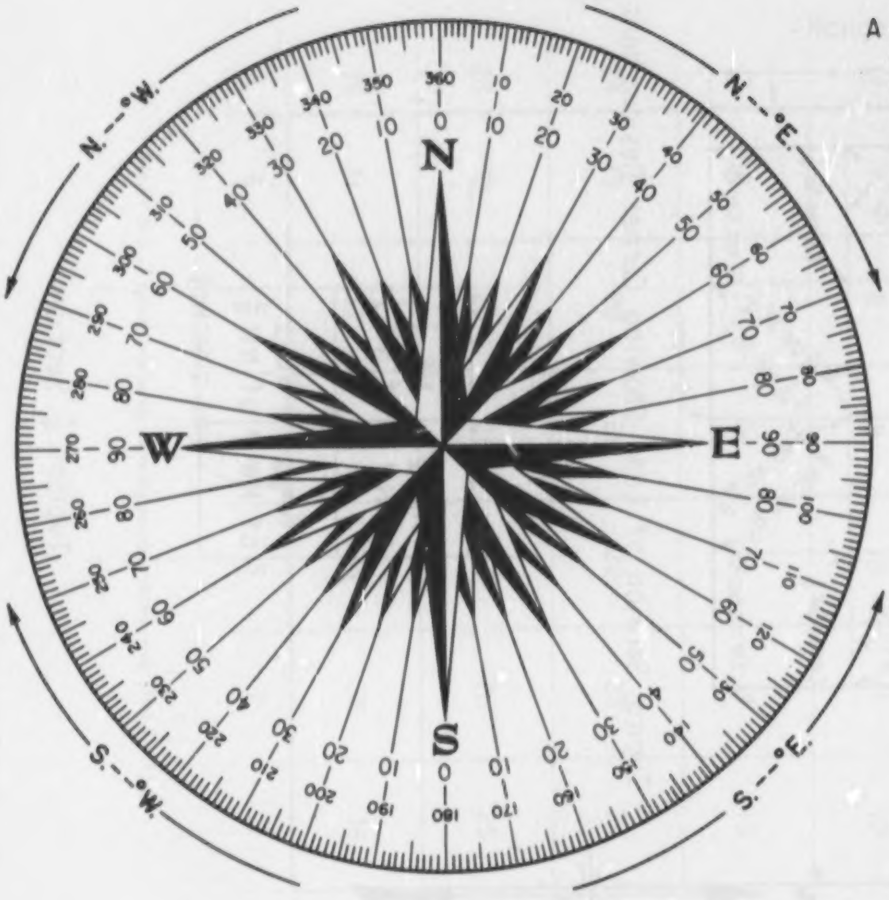

N.--°W.
N.--°E.
S.--°E.
S.--°W.
N
E
S
W
360
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350

A transmission line always runs from left to right on a key map or on a plan-profile drawing. The direction (bearing) of a line, as indicated on the plan-profile drawing, is related to the directions given on an azimuth chart. Examples are:

N 88° 30' 00" E S 62° 36' 47" E

Δ = 28°53'13" Rt.

Δ Indicates the angle turned, and the arrow head indicates the direction of the new segment of the line in relation to the segment just before the angle point.

S 71° 15' 00" W S 48° 09' 00" W

PI Sta. 6304+26.2
Δ = 23°06'00" Lt.

The letters PI (point of intersection) are used as a prefix to a station to denote an angle and to indicate the exact location of the angle point.

Figure B-3.–Azimuth chart. 104-D-1136.

Consider pole as a simple beam

where f = stress in outer fiber N/mm^2 (lb/in^2)

M = maximum moment N·mm (lb-in)

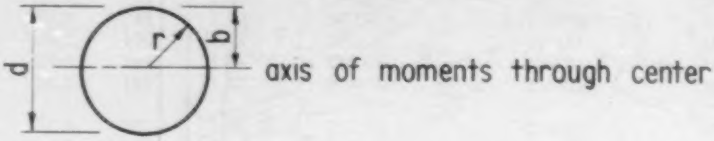
S = section modulus mm^3 (in^3)

J = moment of inertia mm^4 (in^4)

y = distance from center of gravity to outer fiber mm (in)

r = radius of pole cross section mm (in)

c = circumference of pole cross section mm (in)



then
$$b = \frac{d}{2} = r$$
$$J = \frac{\pi d^4}{64} = \frac{\pi r^4}{4}$$
$$S = \frac{J}{y} = \frac{\pi r^4}{4} \cdot \frac{1}{r} = \frac{\pi r^3}{4}$$
$$f = \frac{M}{S}$$
$$M = fS = f\left(\frac{\pi r^3}{4}\right)$$
$$c = 2\pi r$$
$$r = \frac{c}{2\pi}$$
$$r^3 = \frac{c^3}{8\pi^3}$$
$$M = f\left(\frac{\pi}{4}\right)\left(\frac{c^3}{8\pi^3}\right) = f\left(\frac{c^3}{32\pi^2}\right) = 0.003\ 166 fc^3$$

If f is in N/mm^2 and c is in mm, M is in N·mm. Dividing by 1000, M is in N·m. $M = 3.166 \times 10^{-6} fc^3$ N·m.

If f is in lb/in^2 and c is in inches, M is in lb-in. Dividing by 12, M is in lb-ft. $M = 2.638 \times 10^{-4} fc^3$ lb-ft.

Figure B-4.–Development of formula for maximum moment of resistance on wood poles. 104-D-1137.

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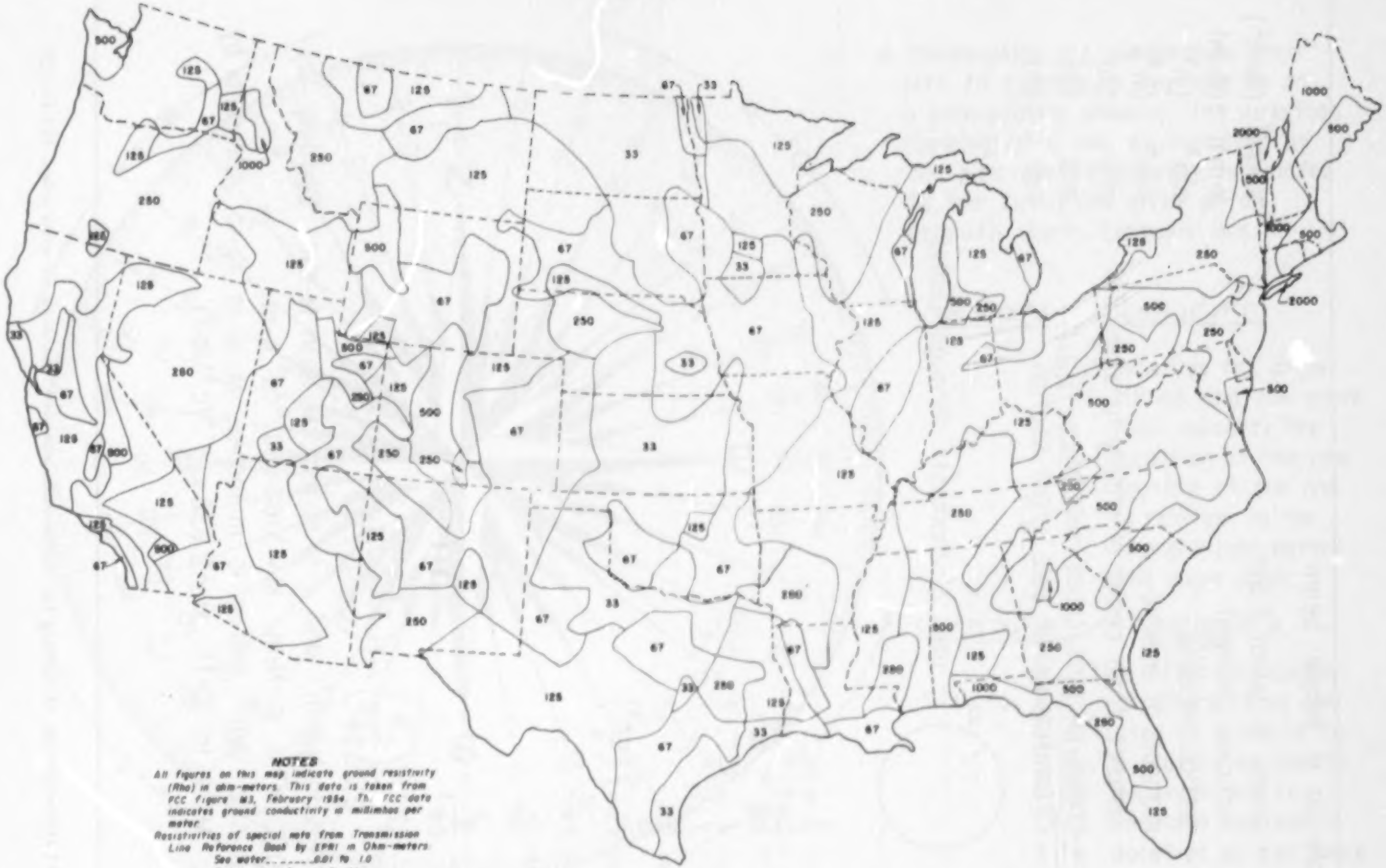
500
125
125
67
67
125
1000
250
250
125
33
67
67
125
900
125
67
125
500
500
67
250
125
33
67
250
250
500
125
67
125
250
67
125
33
33
67
33
125
67
250
67
250
33
125
33
125
67
250
125
67
125
500
250
125
67
250
500
500
1000
1000
500
250
125
500
67
250
500
2000
1500
1000
1500
500
250
2000
250
500
125
500

NOTES

All figures on this map indicate ground resistivity (Rho) in ohm-meters. This data is taken from FCC figure M3, February 1954. Th FCC data indicates ground conductivity in millimhos per meter.

Resistivities of special note from Transmission Line Reference Book by EPRI in Ohm-meters

Sea water..........0.01 to 1.0
Swampy ground.......10 to 100
Pure slate..........10 000 000
Sand stone..........100 000 000

Figure B-5.–Ground resistivity in the United States. 104-D-1138. From 40-D-6456.

Table B-1.–*Maximum moment of resistance for pole circumferences at ground line–USBR standard*

Metric: $M_r = 3.166 \times 10^{-6} f c^3$ (c in mm) U.S. customary: $M_r = 2.638 \times 10^{-4} f c^3$ (c in inches)

Pole Circumference c		Pole Diameter		Western Red Cedar		Douglas Fir and Southern Yellow Pine	
				$f = 38.610\ 88$ MPa	$f = 5600$ lb/in^2	$f = 51.021\ 52$ MPa	$f = 7400$ lb/in^2
mm	in	mm	in	N·m	lb·ft	N·m	lb·ft
508	20.0	162	6.37	16 025	11 818	21 176	15 616
521	20.5	166	6.53	17 287	12 726	22 844	16 817
533	21.0	170	6.68	18 509	13 681	24 459	18 078
546	21.5	174	6.84	19 897	14 681	26 293	19 400
559	22.0	178	7.00	21 352	15 730	28 216	20 786
572	22.5	182	7.16	22 877	16 827	30 230	22 235
584	23.0	186	7.32	24 347	17 974	32 173	23 751
597	23.5	190	7.48	26 010	19 171	34 370	25 334
610	24.0	194	7.64	27 746	20 421	36 665	26 986
622	24.5	198	7.80	29 416	21 725	38 871	28 708
635	25.0	202	7.96	31 299	23 082	41 360	30 501
648	25.5	206	8.12	33 261	24 495	43 953	32 368
660	26.0	210	8.28	35 144	25 964	46 440	34 310
673	26.5	214	8.44	37 261	27 491	49 239	36 328
686	27.0	218	8.59	39 463	29 077	52 147	38 423
699	27.5	222	8.75	41 749	30 722	55 169	40 597
711	28.0	226	8.91	43 936	32 429	58 059	42 852
724	28.5	230	9.07	46 391	34 197	61 302	45 189
737	29.0	235	9.23	48 935	36 029	64 664	47 610
749	29.5	238	9.39	51 364	37 925	67 874	50 115
762	30.0	242	9.55	54 086	39 886	71 470	52 707
775	30.5	247	9.71	56 901	41 914	75 191	55 386
787	31.0	250	9.87	59 586	44 009	78 738	58 155
800	31.5	255	10.03	62 587	46 173	82 705	61 015
813	32.0	259	10.19	65 688	48 407	86 803	63 967
826	32.5	263	10.35	68 890	50 712	91 034	67 012
838	33.0	267	10.50	71 937	53 089	95 059	70 153
851	33.5	271	10.66	75 337	55 538	99 552	73 390
864	34.0	275	10.82	78 842	58 063	104 185	76 726
876	34.5	279	10.98	82 017	60 662	108 586	80 161
889	35.0	283	11.14	85 886	63 338	113 493	83 697
902	35.5	287	11.30	89 709	66 091	118 545	87 335
914	36.0	291	11.46	93 338	68 923	123 339	91 078
927	36.5	295	11.62	97 377	71 835	128 677	94 925
940	37.0	299	11.78	101 532	74 828	134 167	98 880
953	37.5	303	11.94	105 803	77 903	139 811	102 943
965	38.0	307	12.10	109 850	81 061	145 159	107 116
978	38.5	311	12.25	114 350	84 303	151 105	111 400
991	39.0	315	12.41	118 971	87 630	157 211	115 797
1003	39.5	319	12.57	123 345	91 044	162 992	120 308
1016	40.0	323	12.73	128 204	94 545	169 412	124 935
1029	40.5	328	12.89	133 188	98 135	175 999	129 679
1041	41.0	331	13.05	137 902	101 815	182 228	134 542
1054	41.5	336	13.21	143 133	105 586	189 141	139 524
1067	42.0	340	13.37	148 495	109 448	196 226	144 628

Table B-1.–*Maximum moment of resistance for pole circumferences at ground line–USBR standard*–Continued

Pole Circumference c		Pole Diameter		Western Red Cedar		Douglas Fir and Southern Yellow Pine	
				$f = 38.610\ 88$ MPa	$f = 5600$ lb/in^2	$f = 51.021\ 52$ MPa	$f = 7400$ lb/in^2
mm	in	mm	in	N·m	lb·ft	N·m	lb·ft
1080	42.5	344	13.53	153 989	113 404	203 486	149 855
1092	43.0	348	13.69	159 180	117 454	210 345	155 207
1105	43.5	352	13.85	164 932	121 599	217 947	160 684
1118	44.0	356	14.01	170 822	125 840	225 730	166 289
1130	44.5	360	14.16	176 382	130 179	233 077	172 023
1143	45.0	364	14.32	182 540	134 617	241 214	177 886
1156	45.5	368	14.48	188 840	139 154	249 538	183 882
1168	46.0	372	14.64	194 782	143 792	257 390	190 011
1181	46.5	376	14.80	201 358	148 532	266 081	196 275
1194	47.0	380	14.96	208 081	153 375	274 964	202 674
1207	47.5	384	15.12	214 952	158 322	284 044	209 212
1219	48.0	388	15.28	221 427	163 375	292 600	215 888
1232	48.5	392	15.44	228 587	168 534	302 062	222 705
1245	49.0	396	15.60	235 900	173 800	311 725	229 664
1257	49.5	400	15.76	242 787	179 175	320 826	236 767
1270	50.0	404	15.92	250 398	184 660	330 883	244 015
1283	50.5	408	16.07	258 166	190 255	341 149	251 408
1295	51.0	412	16.23	265 478	195 962	350 811	258 950
1308	51.5	416	16.39	273 554	201 782	361 482	266 641
1321	52.0	420	16.55	281 792	207 717	372 368	274 483
1334	52.5	425	16.71	290 193	213 767	383 470	282 477
1346	53.0	428	16.87	298 095	219 933	393 912	290 625
1359	53.5	433	17.03	306 816	226 216	405 436	298 928
1372	54.0	437	17.19	315 706	232 618	417 183	307 388
1384	54.5	440	17.35	324 062	239 140	428 225	316 006
1397	55.0	445	17.51	333 280	245 782	440 406	324 783
1410	55.5	449	17.67	342 671	252 546	452 815	333 722
1422	56.0	453	17.83	351 495	259 434	464 475	342 823
1435	56.5	457	17.98	361 223	266 445	477 331	352 088
1448	57.0	461	18.14	371 130	273 581	490 422	361 518
1461	57.5	465	18.30	381 216	280 844	503 749	371 116
1473	58.0	469	18.46	390 686	288 235	516 264	380 882
1486	58.5	473	18.62	401 122	295 753	530 054	390 817
1499	59.0	477	18.78	411 742	303 402	544 088	400 924
1511	59.5	481	18.94	421 710	311 181	557 259	411 204
1524	60.0	485	19.10	432 688	319 092	571 767	421 657
1537	60.5	489	19.26	443 856	327 136	586 524	432 287
1549	61.0	493	19.42	454 333	335 314	600 369	443 094
1562	61.5	497	19.58	465 868	343 627	615 612	454 079
1575	62.0	501	19.74	477 597	352 077	631 111	465 244
1588	62.5	506	19.89	489 521	360 664	646 868	476 591
1600	63.0	509	20.05	500 703	369 389	661 643	488 121
1613	63.5	513	20.21	513 007	378 254	677 902	499 836
1626	64.0	518	20.37	525 511	387 260	694 425	511 736
1638	64.5	521	20.53	537 232	396 407	709 914	523 824

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Table B-1.–*Maximum moment of resistance for pole circumferences at ground line–USBR standard*–Continued

Pole Circumference *c*		Pole Diameter		Western Red Cedar		Douglas Fir and Southern Yellow Pine	
				$f = 38.610\ 88$ MPa	$f = 5600$ lb/in^2	$f = 51.021\ 52$ MPa	$f = 7400$ lb/in^2
mm	in	mm	in	N·m	lb·ft	N·m	lb·ft
1651	65.0	526	20.69	550 125	405 698	726 951	536 100
1664	65.5	530	20.85	563 223	415 132	744 259	548 567
1676	66.0	534	21.01	575 496	424 712	760 477	561 226
1689	66.5	538	21.17	588 992	434 437	778 311	574 078
1702	67.0	542	21.33	602 697	444 311	796 421	587 125
1715	67.5	546	21.49	616 613	454 332	814 810	600 368
1727	68.0	550	21.65	629 647	464 504	832 034	613 808
1740	68.5	554	21.80	643 974	474 826	850 965	627 448
1753	69.0	558	21.96	658 516	485 299	870 181	641 288
1765	69.5	562	22.12	672 132	495 926	888 174	655 331
1778	70.0	566	22.28	687 093	506 707	907 945	669 577
1791	70.5	570	22.44	702 275	517 642	928 006	684 027
1803	71.0	574	22.60	716 486	528 734	946 785	698 685
1816	71.5	578	22.76	732 096	539 984	967 412	713 550
1829	72.0	582	22.92	747 931	551 391	988 337	728 624
1842	72.5	586	23.08	763 993	562 959	1 009 562	743 910
1854	73.0	590	23.24	779 022	574 687	1 029 422	759 407
1867	73.5	594	23.40	795 524	586 576	1 051 228	775 119
1880	74.0	598	23.55	812 258	598 629	1 073 341	791 045
1892	74.5	602	23.71	827 911	610 845	1 094 026	807 189
1905	75.0	606	23.87	845 095	623 227	1 116 732	823 550
1918	75.5	610	24.03	862 514	635 775	1 139 751	840 131
1930	76.0	614	24.19	878 805	648 490	1 161 278	856 933
1943	76.5	618	24.35	896 683	661 374	1 184 902	873 958
1956	77.0	623	24.51	914 802	674 427	1 208 845	891 207

Table B-2.–*Maximum moment of resistance for pole circumferences at ground line–ANSI standard*

$M_r = 2.64 \times 10^{-4} f c^3$

Pole circumference c, in	Pole diameter, in	Western Red Cedar $f = 6000$ lb/in^2, lb·ft	Southern Yellow Pine $f = 8000$ lb/in^2, lb·ft	Western Larch $f = 8400$ lb/in^2, lb·ft
20.0	6.37	12 672	16 896	17 741
20.5	6.53	13 646	18 195	19 105
21.0	6.68	14 669	19 559	20 537
21.5	6.84	15 742	20 990	22 039
22.0	7.00	16 866	22 488	23 613
22.5	7.16	18 042	24 057	25 259
23.0	7.32	19 272	25 696	26 981
23.5	7.48	20 566	27 409	28 779
24.0	7.64	21 897	29 196	30 656
24.5	7.80	23 294	31 059	32 612
25.0	7.96	24 750	33 000	34 650
25.5	8.12	26 264	35 019	36 770
26.0	8.28	27 840	37 120	38 976
26.5	8.44	29 477	39 303	41 268
27.0	8.59	31 177	41 570	43 649
27.5	8.75	32 942	43 923	46 119
28.0	8.91	34 771	46 362	48 680
28.5	9.07	36 668	48 890	51 335
29.0	9.23	38 632	51 509	54 085
29.5	9.39	40 665	54 220	56 931
30.0	9.55	42 768	57 024	59 875
30.5	9.71	44 942	59 922	62 919
31.0	9.87	47 188	62 918	66 064
31.5	10.03	49 509	66 012	69 313
32.0	10.19	51 904	69 206	72 666
32.5	10.35	54 375	72 501	76 126
33.0	10.50	56 924	75 898	79 693
33.5	10.66	59 551	79 401	83 371
34.0	10.82	62 257	83 010	87 160
34.5	10.98	65 044	86 726	91 062
35.0	11.14	67 914	90 552	95 079
35.5	11.30	70 866	94 488	99 212
36.0	11.46	73 903	98 537	103 464
36.5	11.62	77 025	102 700	107 835
37.0	11.78	80 234	106 979	112 328
37.5	11.94	83 531	111 375	116 943
38.0	12.10	86 917	115 889	121 684
38.5	12.26	90 393	120 524	126 550
39.0	12.41	93 961	125 281	131 545
39.5	12.57	97 621	130 162	136 670
40.0	12.73	101 376	135 168	141 926
40.5	12.89	105 225	140 300	147 315
41.0	13.05	109 170	145 561	152 839
41.5	13.21	113 213	150 951	158 499
42.0	13.37	117 355	156 473	164 297

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Table B-2.–*Maximum moment of resistance for pole circumferences at ground line–ANSI standard*–Continued

Pole Circumference c, in	Pole Diameter, in	Western Red Cedar $f = 6000$ lb/in^2 lb•ft	Southern Yellow Pine $f = 8000$ lb/in^2 lb•ft	Western Larch $f = 8400$ lb/in^2 lb•ft
42.5	13.53	121 596	162 129	170 235
43.0	13.69	125 939	167 918	176 314
43.5	13.85	130 383	173 844	182 537
44.0	14.01	134 931	179 908	188 904
44.5	14.17	139 583	186 111	195 417
45.0	14.32	144 342	192 456	202 078
45.5	14.48	149 207	198 942	208 889
46.0	14.64	154 180	205 573	215 852
46.5	14.80	159 262	212 350	222 967
47.0	14.96	164 455	219 274	230 237
4[illegible].5	15.12	169 760	226 347	237 664
48.0	15.28	175 177	233 570	245 248
48.5	15.44	180 709	240 945	252 992
49.0	15.60	186 356	248 474	260 898
49.5	15.76	192 119	256 158	268 966
50.0	15.92	198 000	264 000	277 200
50.5	16.08	203 999	271 999	285 599
51.0	16.23	210 119	280 158	294 166
51.5	16.39	216 359	288 479	302 903
52.0	16.55	222 723	296 964	311 812
52.5	16.71	229 209	305 613	320 893
53.0	16.87	235 821	314 428	330 149
53.5	17.03	242 558	323 411	339 581
54.0	17.19	249 422	332 563	349 192
54.5	17.35	256 415	341 887	358 982
55.0	17.51	263 538	351 384	368 953
55.5	17.67	270 790	361 054	379 107
56.0	17.83	278 175	370 900	389 466
56.5	17.99	285 693	380 924	399 971
57.0	18.14	293 345	391 127	310 683
57.5	18.30	301 133	401 511	421 586
58.0	18.46	309 057	412 076	432 680
58.5	18.62	317 119	422 825	443 967
59.0	18.78	325 320	433 760	455 448
59.5	18.94	333 661	444 881	467 126
60.0	19.10	342 144	456 192	479 001
60.5	19.26	350 769	467 692	491 076
61.0	19.42	359 537	479 383	503 353
61.5	19.58	368 451	491 268	515 832
62.0	19.74	377 511	503 348	528 516
62.5	19.90	386 718	515 625	541 506
63.0	20.05	396 074	528 099	554 504
63.5	20.21	405 579	540 773	567 811
64.0	20.37	415 236	553 648	581 330
64.5	20.53	425 044	566 725	595 062

Table B-2.–*Maximum moment of resistance for pole circumferences at ground line–ANSI standard*–Continued

Pole Circumference c, in	Pole Diameter, in	Western Red Cedar $f = 6000$ lb/in^2 lb•ft	Southern Yellow Pine $f = 8000$ lb/in^2 lb•ft	Western Larch $f = 8400$ lb/in^2 lb•ft
65.0	20.69	435 006	580 008	609 008
65.5	20.84	445 122	593 496	623 170
66.0	21.00	455 393	607 191	637 551
66.5	21.16	465 822	621 096	652 150
67.0	21.32	476 408	635 211	666 972
67.5	21.48	487 154	649 539	682 015
68.0	21.64	498 060	664 080	697 284
68.5	21.80	509 127	678 837	712 779
69.0	21.96	520 358	693 811	728 501
69.5	22.12	531 752	709 003	744 453
70.0	22.28	543 312	724 416	760 636
70.5	22.44	555 037	740 050	777 052
71.0	22.60	566 931	755 908	793 703
71.5	22.75	578 992	771 990	810 590
72.0	22.91	591 224	788 299	827 714
72.5	23.07	603 627	804 837	845 078
73.0	23.23	616 202	821 603	862 684
73.5	23.39	628 951	838 602	880 532
74.0	23.55	641 874	855 833	898 624
74.5	23.71	654 973	873 298	916 963
75.0	23.87	668 250	891 000	935 550
75.5	24.03	681 704	908 939	954 386
76.0	24.19	695 337	927 117	973 473
76.5	24.35	709 152	945 536	992 813
77.0	24.50	723 148	964 197	1 012 407
77.5	24.66	737 327	983 103	1 032 258
78.0	24.82	751 690	1 002 253	1 052 366
78.5	24.98	766 238	1 021 651	1 072 734
79.0	25.14	780 973	1 041 298	1 093 363
79.5	25.30	795 896	1 061 195	1 114 255
80.0	25.46	811 008	1 081 344	1 135 411
80.5	25.62	826 309	1 101 746	1 156 833
81.0	25.78	841 802	1 122 403	1 178 523
81.5	25.94	857 487	1 143 317	1 200 483
82.0	26.10	873 366	1 164 489	1 222 713
82.5	26.26	889 440	1 185 921	1 245 217
83.0	26.41	905 710	1 207 614	1 267 994
83.5	26.57	922 177	1 229 570	1 291 048
84.0	26.73	938 843	1 251 790	1 314 380
84.5	26.89	955 708	1 274 277	1 337 991
85.0	27.05	972 774	1 297 032	1 361 883
85.5	27.21	990 041	1 320 055	1 386 058

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 30 FOOT POLE

DISTANCE FROM TOP FEET	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	27.00	25.00	23.00	21.00
1	27.40	25.38	23.38	21.33
2	27.79	25.75	23.75	21.67
3	28.19	26.13	24.13	22.00
4	28.58	26.50	24.50	22.33
5	28.98	26.88	24.88	22.67
6	29.38	27.25	25.25	23.00
7	29.77	27.63	25.63	23.33
8	30.17	28.00	26.00	23.67
9	30.56	28.38	26.38	24.00
10	30.96	28.75	26.75	24.33
11	31.35	29.13	27.13	24.67
12	31.75	29.50	27.50	25.00
13	32.15	29.88	27.88	25.33
14	32.54	30.25	28.25	25.67
15	32.94	30.63	28.63	26.00
16	33.33	31.00	29.00	26.33
17	33.73	31.38	29.38	26.67
18	34.12	31.75	29.75	27.00
19	34.52	32.13	30.13	27.33
20	34.92	32.50	30.50	27.67
21	35.31	32.88	30.88	28.00
22	35.71	33.25	31.25	28.33
23	36.10	33.63	31.63	28.67
24	36.50	34.00	32.00	29.00
------GROUND LINE (5 FEET, 6 INCHES)-------				
25	36.90	34.38	32.38	29.33
26	37.29	34.75	32.75	29.67
27	37.69	35.13	33.13	30.00
28	38.08	35.50	33.50	30.33
29	38.48	35.68	33.88	30.67
30	38.87	36.25	34.25	31.00

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 35 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	31.00	29.00	27.00	25.00	23.00	21.00
1	31.43	29.43	27.41	25.40	23.38	21.36
2	31.86	29.86	27.83	25.79	23.76	21.72
3	32.29	30.29	28.24	26.19	24.14	22.09
4	32.72	30.72	28.66	26.59	24.52	22.45
5	33.16	31.16	29.07	26.98	24.90	22.81
6	33.59	31.59	29.48	27.38	25.28	23.17
7	34.02	32.02	29.90	27.78	25.66	23.53
8	34.45	32.45	30.31	28.17	26.03	23.90
9	34.88	32.88	30.72	28.57	26.41	24.26
10	35.31	33.31	31.14	28.97	26.79	24.62

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 35 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
11	35.74	33.74	31.55	29.36	27.17	24.98
12	36.17	34.17	31.97	29.76	27.55	25.34
13	36.60	34.60	32.38	30.16	27.93	25.71
14	37.03	35.03	32.79	30.55	28.31	26.07
15	37.47	35.47	33.21	30.95	28.69	26.43
16	37.90	35.90	33.62	31.34	29.07	26.79
17	38.33	36.33	34.03	31.74	29.45	27.16
18	38.76	36.76	34.45	32.14	29.83	27.52
19	39.19	37.19	34.86	32.53	30.21	27.88
20	39.62	37.62	35.28	32.93	30.59	28.24
21	40.05	38.05	35.69	33.33	30.97	28.60
22	40.48	38.48	36.10	33.72	31.34	28.97
23	40.91	38.91	36.52	34.12	31.72	29.33
24	41.34	39.34	36.93	34.52	32.10	29.69
25	41.78	39.78	37.34	34.91	32.48	30.05
26	42.21	40.21	37.76	35.31	32.86	30.41
27	42.64	40.64	38.17	35.71	33.24	30.78
28	43.07	41.07	38.59	36.10	33.62	31.14
29	43.50	41.50	39.00	36.50	34.00	31.50
----------GROUND LINE (6 FEET, 0 INCHES)----------						
30	43.93	41.93	39.41	36.90	34.38	31.86
31	44.36	42.36	39.83	37.29	34.76	32.22
32	44.79	42.79	40.24	37.69	35.14	32.59
33	45.22	43.22	40.66	38.09	35.52	32.95
34	45.66	43.66	41.07	38.48	35.90	33.31
35	46.09	44.09	41.48	38.88	36.28	33.67

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 40 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.46	31.44	29.43	27.41	25.40	23.38	21.37
2	33.91	31.88	29.85	27.82	25.79	23.76	21.74
3	34.37	32.32	30.28	28.24	26.19	24.15	22.10
4	34.82	32.76	30.71	28.65	26.59	24.53	22.47
5	35.28	33.21	31.13	29.06	26.99	24.91	22.84
6	35.74	33.65	31.56	29.47	27.38	25.29	23.21
7	36.19	34.09	31.99	29.88	27.78	25.68	23.57
8	36.65	34.53	32.41	30.29	28.18	26.06	23.94
9	37.10	34.97	32.84	30.71	28.57	26.44	24.31
10	37.56	35.41	33.26	31.12	28.97	26.82	24.68
11	38.01	35.85	33.69	31.53	29.37	27.21	25.04
12	38.47	36.29	34.12	31.94	29.76	27.59	25.41
13	38.93	36.74	34.54	32.35	30.16	27.97	25.78
14	39.38	37.18	34.97	32.76	30.56	28.35	26.15
15	39.84	37.62	35.40	33.18	30.96	28.74	26.51
16	40.29	38.06	35.82	33.59	31.35	29.12	26.88
17	40.75	38.50	36.25	34.00	31.75	29.50	27.25
18	41.21	38.94	36.68	34.41	32.15	29.88	27.62
19	41.66	39.38	37.10	34.82	32.54	30.26	27.99
20	42.12	39.82	37.53	35.24	32.94	30.65	28.35

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR							40 FOOT POLE—con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
21	42.57	40.26	37.96	35.65	33.34	31.03	28.72
22	43.03	40.71	38.38	36.06	33.74	31.41	29.09
23	43.49	41.15	38.81	36.47	34.13	31.79	29.46
24	43.94	41.59	39.24	36.88	34.53	32.18	29.82
25	44.40	42.03	39.66	37.29	34.93	32.56	30.19
26	44.85	42.47	40.09	37.71	35.32	32.94	30.56
27	45.31	42.91	40.51	38.12	35.72	33.32	30.93
28	45.76	43.35	40.94	38.53	36.12	33.71	31.29
29	46.22	43.79	41.37	38.94	36.51	34.09	31.66
30	46.68	44.24	41.79	39.35	36.91	34.47	32.03
31	47.13	44.68	42.22	39.76	37.31	34.85	32.40
32	47.59	45.12	42.65	40.18	37.71	35.24	32.76
33	48.04	45.56	43.07	40.59	38.10	35.62	33.13
GROUND LINE (6 FEET, 0 INCHES)							
34	48.50	46.00	43.50	41.00	38.50	36.00	33.50
35	48.96	46.44	43.93	41.41	38.90	36.38	33.87
36	49.41	46.88	44.35	41.82	39.29	36.76	34.24
37	49.87	47.32	44.78	42.24	39.69	37.15	34.60
38	50.32	47.76	45.21	42.65	40.09	37.53	34.97
39	50.78	48.21	45.63	43.06	40.49	37.91	35.34
40	51.24	48.65	46.06	43.47	40.88	38.29	35.71

SOUTHERN YELLOW PINE AND DOUGLAS FIR							45 FOOT POLE
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.46	31.45	29.42	27.41	25.40	23.37	21.36
2	33.92	31.90	29.85	27.82	25.79	23.74	21.72
3	34.38	32.35	30.27	28.23	26.19	24.12	22.08
4	34.85	32.79	30.69	28.64	26.59	24.49	22.44
5	35.31	33.24	31.12	29.05	26.99	24.86	22.79
6	35.77	33.69	31.54	29.46	27.38	25.23	23.15
7	36.23	34.14	31.96	29.87	27.78	25.60	23.51
8	36.69	34.59	32.38	30.28	28.18	25.97	23.87
9	37.15	35.04	32.81	30.69	28.58	26.35	24.23
10	37.62	35.49	33.23	31.10	28.97	26.72	24.59
11	38.08	35.94	33.65	31.51	29.37	27.09	24.95
12	38.54	36.38	34.08	31.92	29.77	27.46	25.31
13	39.00	36.83	34.50	32.33	30.17	27.83	25.67
14	39.46	37.28	34.92	32.74	30.56	28.21	26.03
15	39.92	37.73	35.35	33.15	30.96	28.58	26.38
16	40.38	38.18	35.77	33.56	31.36	28.95	26.74
17	40.85	38.63	36.19	33.97	31.76	29.32	27.10
18	41.31	39.08	36.62	34.38	32.15	29.69	27.46
19	41.77	39.53	37.04	34.79	32.55	30.06	27.82
20	42.23	39.97	37.46	35.21	32.95	30.44	28.18

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 45 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
21	42.69	40.42	37.88	35.62	33.35	30.81	28.54
22	43.15	40.87	38.31	36.03	33.74	31.18	28.90
23	43.62	41.32	38.73	36.44	34.14	31.55	29.26
24	44.08	41.77	39.15	36.85	34.54	31.92	29.62
25	44.54	42.22	39.58	37.26	34.94	32.29	29.97
26	45.00	42.67	40.00	37.67	35.33	32.67	30.33
27	45.46	43.12	40.42	38.08	35.73	33.04	30.69
28	45.92	43.56	40.85	38.49	36.13	33.41	31.05
29	46.38	44.01	41.27	38.90	36.53	33.78	31.41
30	46.85	44.46	41.69	39.31	36.92	34.15	31.77
31	47.31	44.91	42.12	39.72	37.32	34.53	32.13
32	47.77	45.36	42.54	40.13	37.72	34.90	32.49
33	48.23	45.81	42.96	40.54	38.12	35.27	32.85
34	48.69	46.26	43.38	40.95	38.51	35.64	33.21
35	49.15	46.71	43.81	41.36	38.91	36.01	33.56
36	49.62	47.15	44.23	41.77	39.31	36.38	33.92
37	50.08	47.60	44.65	42.18	39.71	36.76	34.28
38	50.54	48.05	45.08	42.59	40.10	37.13	34.64
GROUND LINE (6 FEET, 6 INCHES)							
39	51.00	48.50	45.50	43.00	40.50	37.50	35.00
40	51.46	48.95	45.92	43.41	40.90	37.87	35.36
41	51.92	49.40	46.35	43.82	41.29	38.24	35.72
42	52.38	49.85	46.77	44.23	41.69	38.62	36.08
43	52.85	50.29	47.19	44.64	42.09	38.99	36.44
44	53.31	50.74	47.62	45.05	42.49	39.36	36.79
45	53.77	51.19	48.04	45.46	42.88	39.73	37.15

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 50 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.45	31.44	29.42	27.41	25.39	23.36	21.35
2	33.91	31.89	29.84	27.82	25.77	23.73	21.70
3	34.36	32.33	30.26	28.23	26.16	24.09	22.06
4	34.82	32.77	30.68	28.64	26.55	24.45	22.41
5	35.27	33.22	31.10	29.05	26.93	24.82	22.76
6	35.73	33.66	31.52	29.45	27.32	25.18	23.11
7	36.18	34.10	31.94	29.86	27.70	25.55	23.47
8	36.64	34.55	32.36	30.27	28.09	25.91	23.82
9	37.09	34.99	32.78	30.68	28.48	26.27	24.17
10	37.55	35.43	33.20	31.09	28.86	26.64	24.52
11	38.00	35.88	33.63	31.50	29.25	27.00	24.87
12	38.45	36.32	34.05	31.91	29.64	27.36	25.23
13	38.91	36.76	34.47	32.32	30.02	27.73	25.58
14	39.36	37.20	34.89	32.73	30.41	28.09	25.93
15	39.82	37.65	35.31	33.14	30.80	28.45	26.28
16	40.27	38.09	35.73	33.55	31.18	28.82	26.64
17	40.73	38.53	36.15	33.95	31.57	29.18	26.99
18	41.18	38.98	36.57	34.36	31.95	29.55	27.34
19	41.64	39.42	36.99	34.77	32.34	29.91	27.69
20	42.09	39.86	37.41	35.18	32.73	30.27	28.05

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 50 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
21	42.55	40.31	37.83	35.59	33.11	30.64	28.40
22	43.00	40.75	38.25	36.00	33.50	31.00	28.75
23	43.45	41.19	38.67	36.41	33.89	31.36	29.10
24	43.91	41.64	39.09	36.82	34.27	31.73	29.45
25	44.36	42.08	39.51	37.23	34.66	32.09	29.81
26	44.82	42.52	39.93	37.64	35.05	32.45	30.16
27	45.27	42.97	40.35	38.05	35.43	32.82	30.51
28	45.73	43.41	40.77	38.45	35.82	33.18	30.86
29	46.18	43.85	41.19	38.86	36.20	33.55	31.22
30	46.64	44.30	41.61	39.27	36.59	33.91	31.57
31	47.09	44.74	42.03	39.68	36.98	34.27	31.92
32	47.55	45.18	42.45	40.09	37.36	34.64	32.27
33	48.00	45.62	42.87	40.50	37.75	35.00	32.62
34	48.45	46.07	43.30	40.91	38.14	35.36	32.98
35	48.91	46.51	43.72	41.32	38.52	35.73	33.33
36	49.36	46.95	44.14	41.73	38.91	36.09	33.68
37	49.82	47.40	44.56	42.14	39.30	36.45	34.03
38	50.27	47.84	44.98	42.55	39.68	36.82	34.39
39	50.73	48.28	45.40	42.95	40.07	37.18	34.74
40	51.18	48.73	45.82	43.36	40.45	37.55	35.09
41	51.64	49.17	46.24	43.77	40.84	37.91	35.44
42	52.09	49.61	46.66	44.18	41.23	38.27	35.80
----------GROUND LINE (7 FEET, 0 INCHES)----------							
43	52.55	50.06	47.08	44.59	41.61	38.64	36.15
44	53.00	50.50	47.50	45.00	42.00	39.00	36.50
45	53.45	50.94	47.92	45.41	42.39	39.36	36.85
46	53.91	51.39	48.34	45.82	42.77	39.73	37.20
47	54.36	51.83	48.76	46.23	43.16	40.09	37.56
48	54.82	52.27	49.18	46.64	43.55	40.45	37.91
49	55.27	52.72	49.60	47.05	43.93	40.82	38.26
50	55.73	53.16	50.02	47.45	44.32	41.18	38.61

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 55 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.45	31.43	29.42	27.40	25.38	23.36	21.35
2	33.90	31.86	29.84	27.80	25.76	23.7[illegible]	21.69
3	34.35	32.29	30.26	28.19	26.13	24.07	22.04
4	34.80	32.71	30.67	28.59	26.51	24.43	22.39
5	35.24	33.14	31.09	28.99	26.89	24.79	22.73
6	35.69	33.57	31.51	29.39	27.27	25.14	23.08
7	36.14	34.00	31.93	29.79	27.64	25.50	23.43
8	36.59	34.43	32.35	30.18	28.02	25.86	23.78
9	37.04	34.86	32.77	30.58	28.40	26.21	24.12
10	37.49	35.29	33.18	30.98	28.78	26.57	24.47

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR						55 FOOT POLE–con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
11	37.94	35.71	33.60	31.38	29.15	26.93	24.82
12	38.39	36.14	34.02	31.78	29.53	27.29	25.16
13	38.84	36.57	34.44	32.17	29.91	27.64	25.51
14	39.29	37.00	34.86	32.57	30.29	28.00	25.86
15	39.73	37.43	35.28	32.97	30.66	28.36	26.20
16	40.18	37.86	35.69	33.37	31.04	28.71	26.55
17	40.63	38.29	36.11	33.77	31.42	29.07	26.90
18	41.08	38.71	36.53	34.16	31.80	29.43	27.24
19	41.53	39.14	36.95	34.56	32.17	29.79	27.59
20	41.98	39.57	37.37	34.96	32.55	30.14	27.94
21	42.43	40.00	37.79	35.36	32.93	30.50	28.29
22	42.88	40.43	38.20	35.76	33.31	30.86	28.63
23	43.33	40.86	38.62	36.15	33.68	31.21	28.98
24	43.78	41.29	39.04	36.55	34.06	31.57	29.33
25	44.22	41.71	39.46	36.95	34.44	31.93	29.67
26	44.67	42.14	39.88	37.35	34.82	32.29	30.02
27	45.12	42.57	40.30	37.74	35.19	32.64	30.37
28	45.57	43.00	40.71	38.14	35.57	33.00	30.71
29	46.02	43.43	41.13	38.54	35.95	33.36	31.06
30	46.47	43.86	41.55	38.94	36.33	33.71	31.41
31	46.92	44.29	41.97	39.34	36.70	34.07	31.76
32	47.37	44.71	42.39	39.73	37.08	34.43	32.10
33	47.82	45.14	42.81	40.13	37.46	34.79	32.45
34	48.27	45.57	43.22	40.53	37.84	35.14	32.80
35	48.71	46.00	43.64	40.93	38.21	35.50	33.14
36	49.16	46.43	44.06	41.33	38.59	35.86	33.49
37	49.61	46.86	44.48	41.72	38.97	36.21	33.84
38	50.06	47.29	44.90	42.12	39.35	36.57	34.18
39	50.51	47.71	45.32	42.52	39.72	36.93	34.53
40	50.96	48.14	45.73	42.92	40.10	37.29	34.88
41	51.41	48.57	46.15	43.32	40.48	37.64	35.22
42	51.86	49.00	46.57	43.71	40.86	38.00	35.57
43	52.31	49.43	46.99	44.11	41.23	38.36	35.92
44	52.76	49.86	47.41	44.51	41.61	38.71	36.27
45	53.20	50.29	47.83	44.91	41.99	39.07	36.61
46	53.65	50.71	48.24	45.31	42.37	39.43	36.96
47	54.10	51.14	48.66	45.70	42.74	39.79	37.31
----------------------GROUND LINE (7 FEET, 6 INCHES)----------------------							
48	54.55	51.57	49.08	46.10	43.12	40.14	37.65
49	55.00	52.00	49.50	46.50	43.50	40.50	38.00
50	55.45	52.43	49.92	45.90	43.88	40.86	38.35
51	55.90	52.86	50.34	47.30	44.26	41.21	38.69
52	56.35	53.29	50.76	47.69	44.63	41.57	39.04
53	56.80	53.71	51.17	48.09	45.01	41.93	39.39
54	57.24	54.14	51.59	48.49	45.39	42.29	39.73
55	57.69	54.57	52.01	48.89	45.77	42.64	40.08

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR						60 FOOT POLE	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.44	31.43	29.41	27.39	25.37	23.35	21.33
2	33.89	31.85	29.81	27.78	25.74	23.70	21.67
3	34.33	32.28	30.22	28.17	26.11	24.06	22.00
4	34.78	32.70	30.63	28.56	26.48	24.41	22.33
5	35.22	33.13	31.04	28.94	26.85	24.76	22.67
6	35.67	33.56	31.44	29.33	27.22	25.11	23.00
7	36.11	33.98	31.85	29.72	27.59	25.46	23.33
8	36.56	34.41	32.26	30.11	27.96	25.81	23.67
9	37.00	34.83	32.67	30.50	28.33	26.17	24.00
10	37.44	35.26	33.07	30.89	28.70	26.52	24.33
11	37.89	35.69	33.48	31.28	29.07	26.87	24.67
12	38.33	36.11	33.89	31.67	29.44	27.22	25.00
13	38.78	36.54	34.30	32.06	29.81	27.57	25.33
14	39.22	36.96	34.70	32.44	30.19	27.93	25.67
15	39.67	37.39	35.11	32.83	30.56	28.28	26.00
16	40.11	37.81	35.52	33.22	30.93	28.63	26.33
17	40.56	38.24	35.93	33.61	31.30	28.98	26.67
18	41.00	38.67	36.33	34.00	31.67	29.33	27.00
19	41.44	39.09	36.74	34.39	32.04	29.69	27.33
20	41.89	39.52	37.15	34.78	32.41	30.04	27.67
21	42.33	39.94	37.56	35.17	32.78	30.39	28.00
22	42.78	40.37	37.96	35.56	33.15	30.74	28.33
23	43.22	40.80	38.37	35.94	33.52	31.09	28.67
24	43.67	41.22	38.78	36.33	33.89	31.44	29.00
25	44.11	41.65	39.19	36.72	34.26	31.80	29.33
26	44.56	42.07	39.59	37.11	34.63	32.15	29.67
27	45.00	42.50	40.00	37.50	35.00	32.50	30.00
28	45.44	42.93	40.41	37.89	35.37	32.85	30.33
29	45.89	43.35	40.81	38.28	35.74	33.20	30.67
30	46.33	43.78	41.22	38.67	36.11	33.56	31.00
31	46.78	44.20	41.63	39.06	36.48	33.91	31.33
32	47.22	44.63	42.04	39.44	36.85	34.26	31.67
33	47.67	45.06	42.44	39.83	37.22	34.61	32.00
34	48.11	45.48	42.85	40.22	37.59	34.96	32.33
35	48.56	45.91	43.26	40.61	37.96	35.31	32.67
36	49.00	46.33	43.67	41.00	38.33	35.67	33.00
37	49.44	46.76	44.07	41.39	38.70	36.02	33.33
38	49.89	47.19	44.48	41.78	39.07	36.37	33.67
39	50.33	47.61	44.89	42.17	39.44	36.72	34.00
40	50.78	48.04	45.30	42.56	39.81	37.07	34.33
41	51.22	48.46	45.70	42.94	40.19	37.43	34.67
42	51.67	48.89	46.11	43.33	40.56	37.78	35.00
43	52.11	49.31	46.52	43.72	40.93	38.13	35.33
44	52.56	49.74	46.93	44.11	41.30	38.48	35.67
45	53.00	50.17	47.33	44.50	41.67	38.83	36.00
46	53.44	50.59	47.74	44.89	42.04	39.19	36.33
47	53.89	51.02	48.15	45.28	42.41	39.54	36.67
48	54.33	51.44	48.56	45.67	42.78	39.89	37.00
49	54.78	51.87	48.96	46.06	43.15	40.24	37.33
50	55.22	52.30	49.37	46.44	43.52	40.59	37.67

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR						60 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
51	55.67	52.72	49.78	46.83	43.89	40.94	38.00
--------------------GROUND LINE (8 FEET, 0 INCHES)--------------------							
52	56.11	53.15	50.19	47.22	44.26	41.30	38.33
53	56.56	53.57	50.59	47.61	44.63	41.65	38.67
54	57.00	54.00	51.00	48.00	45.00	42.00	39.00
55	57.44	54.43	51.41	48.39	45.37	42.35	39.33
56	57.89	54.85	51.81	48.78	45.74	42.70	39.67
57	58.33	55.28	52.22	49.17	46.11	43.06	40.00
58	58.78	55.70	52.63	49.56	46.48	43.41	40.33
59	59.22	56.13	53.04	49.94	46.85	43.76	40.67
60	59.67	56.56	53.44	50.33	47.22	44.11	41.00

SOUTHERN YELLOW PINE AND DOUGLAS FIR						55 FOOT POLE	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.43	31.42	29.40	27.38	25.36	23.35	21.33
2	33.86	31.83	29.80	27.76	25.73	23.69	21.66
3	34.30	32.25	30.19	28.14	26.09	24.04	21.99
4	34.73	32.66	30.59	28.53	26.46	24.39	22.32
5	35.16	33.08	30.99	28.91	26.82	24.74	22.65
6	35.59	33.49	31.39	29.29	27.19	25.08	22.98
7	36.03	33.91	31.79	29.67	27.55	25.43	23.31
8	36.46	34.32	32.19	30.05	27.92	25.78	23.64
9	36.89	34.74	32.58	30.43	28.28	26.13	23.97
10	37.32	35.15	32.98	30.81	28.64	26.47	24.31
11	37.75	35.57	33.38	31.19	29.01	26.82	24.64
12	38.19	35.98	33.78	31.58	29.37	27.17	24.97
13	38.62	36.40	34.18	31.96	29.74	27.52	25.30
14	39.05	36.81	34.58	32.34	30.10	27.86	25.63
15	39.48	37.23	34.97	32.72	30.47	28.21	25.96
16	39.92	37.64	35.37	33.10	30.83	28.56	26.29
17	40.35	38.06	35.77	33.48	31.19	28.91	26.62
18	40.78	38.47	36.17	33.86	31.56	29.25	26.95
19	41.21	38.89	36.57	34.25	31.92	29.60	27.28
20	41.64	39.31	36.97	34.63	32.29	29.95	27.61
21	42.08	39.72	37.36	35.01	32.65	30.30	27.94
22	42.51	40.14	37.76	35.39	33.02	30.64	28.27
23	42.94	40.55	38.16	35.77	33.38	30.99	28.60
24	43.37	40.97	38.56	36.15	33.75	31.34	28.93
25	43.81	41.38	38.96	36.53	34.11	31.69	29.26
26	44.24	41.80	39.36	36.92	34.47	32.03	29.59
27	44.67	42.21	39.75	37.30	34.84	32.38	29.92
28	45.10	42.63	40.15	37.68	35.20	32.73	30.25
29	45.53	43.04	40.55	38.06	35.57	33.08	30.58
30	45.97	43.46	40.95	38.44	35.93	33.42	30.92

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Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR						65 FOOT POLE—**con.**	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
31	46.40	43.87	41.35	38.82	36.30	33.77	31.25
32	46.83	44.29	41.75	39.20	36.66	34.12	31.58
33	47.26	44.70	42.14	39.58	37.03	34.47	31.91
34	47.69	45.12	42.54	39.97	37.39	34.81	32.24
35	48.13	45.53	42.94	40.35	37.75	35.16	32.57
36	48.56	45.95	43.34	40.73	38.12	35.51	32.90
37	48.99	46.36	43.74	41.11	38.48	35.86	33.23
38	49.42	46.78	44.14	41.49	38.85	36.20	33.56
39	49.86	47.19	44.53	41.87	39.21	36.55	33.89
40	50.29	47.61	44.93	42.25	39.58	36.90	34.22
41	50.72	48.03	45.33	42.64	39.94	37.25	34.55
42	51.15	48.44	45.73	43.02	40.31	37.59	34.88
43	51.58	48.86	46.13	43.40	40.67	37.94	35.21
44	52.02	49.27	46.53	43.78	41.03	38.29	35.54
45	52.45	49.69	46.92	44.16	41.40	38.64	35.87
46	52.88	50.10	47.32	44.54	41.76	38.98	36.20
47	53.31	50.52	47.72	44.92	42.13	39.33	36.53
48	53.75	50.93	48.12	45.31	42.49	39.68	36.86
49	54.18	51.35	48.52	45.69	42.86	40.03	37.19
50	54.61	51.76	48.92	46.07	43.22	40.37	37.53
51	55.04	52.18	49.31	46.45	43.58	40.72	37.86
52	55.47	52.59	49.71	46.83	43.95	41.07	38.19
53	55.91	53.01	50.11	47.21	44.31	41.42	38.52
54	56.34	53.42	50.51	47.59	44.68	41.76	38.85
55	56.77	53.84	50.91	47.97	45.04	42.11	39.18
56	57.20	54.25	51.31	48.36	45.41	42.46	39.51
----GROUND LINE (8 FEET, 6 INCHES)----							
57	57.64	54.67	51.70	48.74	45.77	42.81	39.84
58	58.07	55.08	52.10	49.12	46.14	43.15	40.17
59	58.50	55.50	52.50	49.50	46.50	43.50	40.50
60	58.93	55.92	52.90	49.88	46.86	43.85	40.83
61	59.36	56.33	53.30	50.26	47.23	44.19	41.16
62	59.80	56.75	53.69	50.64	47.59	44.54	41.49
63	60.23	57.16	54.09	51.03	47.96	44.89	41.82
64	60.66	57.58	54.49	51.41	48.32	45.24	42.15
65	61.09	57.99	54.89	51.79	48.69	45.58	42.48

SOUTHERN YELLOW PINE AND DOUGLAS FIR						70 FOOT POLE	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.43	31.41	29.39	27.38	25.36	23.34	21.32
2	33.86	31.81	29.78	27.75	25.72	23.69	21.64
3	34.29	32.22	30.17	28.13	26.08	24.03	21.96
4	34.72	32.63	30.56	28.50	26.44	24.38	22.28
5	35.15	33.03	30.95	28.88	26.80	24.72	22.60
6	35.58	33.44	31.34	29.25	27.16	25.06	22.92
7	36.01	33.84	31.73	29.63	27.52	25.41	23.24
8	36.44	34.25	32.13	30.00	27.88	25.75	23.56
9	36.87	34.66	32.52	30.38	28.23	26.09	23.88
10	37.30	35.06	32.91	30.75	28.59	26.44	24.20

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR						70 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
11	37.73	35.47	33.30	31.13	28.95	26.78	24.52
12	38.16	35.88	33.69	31.50	29.31	27.13	24.84
13	38.59	36.28	34.08	31.88	29.67	27.47	25.16
14	39.02	36.69	34.47	32.25	30.03	27.81	25.48
15	39.45	37.09	34.86	32.63	30.39	28.16	25.80
16	39.88	37.50	35.25	33.00	30.75	28.50	26.13
17	40.30	37.91	35.64	33.38	31.11	28.84	26.45
18	40.73	38.31	36.03	33.75	31.47	29.19	26.77
19	41.16	38.72	36.42	34.13	31.83	29.53	27.09
20	41.59	39.13	36.81	34.50	32.19	29.88	27.41
21	42.02	39.53	37.20	34.88	32.55	30.22	27.73
22	42.45	39.94	37.59	35.25	32.91	30.56	28.05
23	42.88	40.34	37.98	35.63	33.27	30.91	28.37
24	43.31	40.75	38.38	36.00	33.63	31.25	28.69
25	43.74	41.16	38.77	36.38	33.98	31.59	29.01
26	44.17	41.56	39.16	36.75	34.34	31.94	29.33
27	44.60	41.97	39.55	37.13	34.70	32.28	29.65
28	45.03	42.38	39.94	37.50	35.06	32.63	29.97
29	45.46	42.78	40.33	37.88	35.42	32.97	30.29
30	45.89	43.19	40.72	38.25	35.78	33.31	30.61
31	46.32	43.59	41.11	38.63	36.14	33.66	30.93
32	46.75	44.00	41.50	39.00	36.50	34.00	31.25
33	47.18	44.41	41.89	39.38	36.86	34.34	31.57
34	47.61	44.81	42.28	39.75	37.22	34.69	31.89
35	48.04	45.22	42.67	40.13	37.58	35.03	32.21
36	48.47	45.63	43.06	40.50	37.94	35.38	32.53
37	48.90	46.03	43.45	40.88	38.30	35.72	32.85
38	49.33	46.44	43.84	41.25	38.66	36.06	33.17
39	49.76	46.84	44.23	41.63	39.02	36.41	33.49
40	50.19	47.25	44.63	42.00	39.38	36.75	33.81
41	50.62	47.66	45.02	42.38	39.73	37.09	34.13
42	51.05	48.06	45.41	42.75	40.09	37.44	34.45
43	51.48	48.47	45.80	43.13	40.45	37.78	34.77
44	51.91	48.88	46.19	43.50	40.81	38.13	35.09
45	52.34	49.28	46.58	43.88	41.17	38.47	35.41
46	52.77	49.69	46.97	44.25	41.53	38.81	35.73
47	53.20	50.09	47.36	44.63	41.89	39.16	36.05
48	53.63	50.50	47.75	45.00	42.25	39.50	36.38
49	54.05	50.91	48.14	45.38	42.61	39.84	36.70
50	54.48	51.31	48.53	45.75	42.97	40.19	37.02
51	54.91	51.72	48.92	46.13	43.33	40.53	37.34
52	55.34	52.13	49.31	46.50	43.69	40.88	37.66
53	55.77	52.53	49.70	46.88	44.05	41.22	37.98
54	56.20	52.94	50.09	47.25	44.41	41.56	38.30
55	56.63	53.34	50.48	47.63	44.77	41.91	38.62
56	57.06	53.75	50.88	48.00	45.13	42.25	38.94
57	57.49	54.16	51.27	48.38	45.48	42.59	39.26
58	57.92	54.56	51.66	48.75	45.84	42.94	39.58
59	58.35	54.97	52.05	49.13	46.20	43.28	39.90
60	58.78	55.38	52.44	49.50	46.56	43.63	40.22

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 70 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
-----GROUND LINE (9 FEET, 0 INCHES)-----							
61	59.21	55.78	52.83	49.88	46.92	43.97	40.54
62	59.64	56.19	53.22	50.25	47.28	44.31	40.86
63	60.07	56.59	53.61	50.63	47.64	44.66	41.18
64	60.50	57.00	54.00	51.00	48.00	45.00	41.50
65	60.93	57.41	54.39	51.38	48.3	45.34	41.82
66	61.36	57.81	54.78	51.75	48.72	45.69	42.14
67	61.79	58.22	55.17	52.13	49.08	46.03	42.46
68	62.22	58.63	55.56	52.50	49.44	46.38	42.78
69	62.65	59.03	55.95	52.88	49.80	46.72	43.10
70	63.08	59.44	56.34	53.25	50.16	47.06	43.42

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 75 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.42	31.41	29.38	27.37	25.35	23.33
2	33.84	31.81	29.77	27.74	25.70	23.67
3	34.26	32.22	30.15	28.11	26.04	24.00
4	34.68	32.62	30.54	28.48	26.39	24.33
5	35.10	33.03	30.92	28.85	26.74	24.67
6	35.52	33.43	31.30	29.22	27.09	25.00
7	35.94	33.84	31.69	29.59	27.43	25.33
8	36.36	34.25	32.07	29.96	27.78	25.67
9	36.78	34.65	32.46	30.33	28.13	26.00
10	37.20	35.06	32.84	30.70	28.48	26.33
11	37.62	35.46	33.22	31.07	28.83	26.67
12	38.04	35.87	33.61	31.43	29.17	27.00
13	38.46	36.28	33.99	31.80	29.52	27.33
14	38.88	36.68	34.38	32.17	29.87	27.67
15	39.30	37.09	34.76	32.54	30.22	28.00
16	39.72	37.49	35.14	32.91	30.57	28.33
17	40.14	37.90	35.53	33.28	30.91	28.67
18	40.57	38.30	35.91	33.65	31.26	29.00
19	40.99	38.71	36.30	34.02	31.61	29.33
20	41.41	39.12	36.68	34.39	31.96	29.67
21	41.83	39.52	37.07	34.76	32.30	30.00
22	42.25	39.93	37.45	35.13	32.65	30.33
23	42.67	40.33	37.83	35.50	33.00	30.67
24	43.09	40.74	38.22	35.87	33.35	31.00
25	43.51	41.14	38.60	36.24	33.70	31.33
26	43.93	41.55	38.99	36.61	34.04	31.67
27	44.35	41.96	39.37	36.98	34.39	32.00
28	44.77	42.36	39.75	37.35	34.74	32.33
29	45.19	42.77	40.14	37.72	35.09	32.67
30	45.61	43.17	40.52	38.09	35.43	33.00

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR					75 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
31	46.03	43.58	40.91	38.46	35.78	33.33
32	46.45	43.99	41.29	38.83	36.13	33.67
33	46.87	44.39	41.67	39.20	36.48	34.00
34	47.29	44.80	42.06	39.57	36.83	34.33
35	47.71	45.20	42.44	39.93	37.17	34.67
36	48.13	45.61	42.83	40.30	37.52	35.00
37	48.55	46.01	43.21	40.67	37.87	35.33
38	48.97	46.42	43.59	41.04	38.22	35.67
39	49.39	46.83	43.98	41.41	38.57	36.00
40	49.81	47.23	44.36	41.78	38.91	36.33
41	50.23	47.64	44.75	42.15	39.26	36.67
42	50.65	48.04	45.13	42.52	39.61	37.00
43	51.07	48.45	45.51	42.89	39.96	37.33
44	51.49	48.86	45.90	43.26	40.30	37.67
45	51.91	49.26	46.28	43.63	40.65	38.00
46	52.33	49.67	46.67	44.00	41.00	38.33
47	52.75	50.07	47.05	44.37	41.35	38.67
48	53.17	50.48	47.43	44.74	41.70	39.00
49	53.59	50.88	47.82	45.11	42.04	39.33
50	54.01	51.29	48.20	45.46	42.39	39.67
51	54.43	51.70	48.59	45.85	42.74	40.00
52	54.86	52.10	48.97	46.22	43.09	40.33
53	55.28	52.51	49.36	46.59	43.43	40.67
54	55.70	52.91	49.74	46.96	43.78	41.00
55	56.12	53.32	50.12	47.33	44.13	41.33
56	56.54	53.72	50.51	47.70	44.48	41.67
57	56.96	54.13	50.89	48.07	44.83	42.00
58	57.38	54.54	51.28	48.43	45.17	42.33
59	57.80	54.94	51.66	48.80	45.52	42.67
60	58.22	55.35	52.04	49.17	45.87	43.00
61	58.64	55.75	52.43	49.54	46.22	43.33
62	59.06	56.16	52.81	49.91	46.57	43.67
63	59.48	56.57	53.20	50.28	46.91	44.00
64	59.90	56.97	53.58	50.65	47.26	44.33
65	60.32	57.38	53.96	51.02	47.61	44.67
------------------GROUND LINE (9 FEET, 6 INCHES)------------------						
66	60.74	57.78	54.35	51.39	47.96	45.00
67	61.16	58.19	54.73	51.76	48.30	45.33
68	61.58	58.59	55.12	52.13	48.65	45.67
69	62.00	59.00	55.50	52.50	49.00	46.00
70	62.42	59.41	55.88	52.87	49.35	46.33
71	62.84	59.81	56.27	53.24	49.70	46.67
72	63.26	60.22	56.65	53.61	50.04	47.00
73	63.68	60.62	57.04	53.98	50.39	47.33
74	64.10	61.03	57.42	54.35	50.74	47.67
75	64.52	61.43	57.80	54.72	51.09	48.00

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Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR						80 FOOT POLE
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.41	31.39	29.38	27.36	25.34	23.32
2	33.82	31.78	29.76	27.73	25.69	23.65
3	34.24	32.18	30.14	28.09	26.03	23.97
4	34.65	32.57	30.51	28.46	26.38	24.30
5	35.06	32.96	30.89	28.82	26.72	24.62
6	35.47	33.35	31.27	29.19	27.07	24.95
7	35.89	33.74	31.65	29.55	27.41	25.27
8	36.30	34.14	32.03	29.92	27.76	25.59
9	36.71	34.53	32.41	30.28	28.10	25.92
10	37.12	34.92	32.78	30.65	28.45	26.24
11	37.53	35.31	33.16	31.01	28.79	26.57
12	37.95	35.70	33.54	31.38	29.14	26.89
13	38.36	36.09	33.92	31.74	29.48	27.22
14	38.77	36.49	34.30	32.11	29.82	27.54
15	39.18	36.88	34.68	32.47	30.17	27.86
16	39.59	37.27	35.05	32.84	30.51	28.19
17	40.01	37.66	35.43	33.20	30.86	28.51
18	40.42	38.05	35.81	33.57	31.20	28.84
19	40.83	38.45	36.19	33.93	31.55	29.16
20	41.24	38.84	36.57	34.30	31.89	29.49
21	41.66	39.23	36.95	34.66	32.24	29.81
22	42.07	39.62	37.32	35.03	32.58	30.14
23	42.48	40.01	37.70	35.39	32.93	30.46
24	42.89	40.41	38.08	35.76	33.27	30.78
25	43.30	40.80	38.46	36.12	33.61	31.11
26	43.72	41.19	38.84	36.49	33.96	31.43
27	44.13	41.58	39.22	36.85	34.30	31.76
28	44.54	41.97	39.59	37.22	34.65	32.08
29	44.95	42.36	39.97	37.58	34.99	32.41
30	45.36	42.76	40.35	37.95	35.34	32.73
31	45.78	43.15	40.73	38.31	35.68	33.05
32	46.19	43.54	41.11	38.68	36.03	33.38
33	46.60	43.93	41.49	39.04	36.37	33.70
34	47.01	44.32	41.86	39.41	36.72	34.03
35	47.43	44.72	42.24	39.77	37.06	34.35
36	47.84	45.11	42.62	40.14	37.41	34.68
37	48.25	45.50	43.00	40.50	37.75	35.00
38	48.66	45.89	43.38	40.86	38.09	35.32
39	49.07	46.28	43.76	41.23	38.44	35.65
40	49.49	46.68	44.14	41.59	38.78	35.97
41	49.90	47.07	44.51	41.96	39.13	36.30
42	50.31	47.46	44.89	42.32	39.47	36.62
43	50.72	47.85	45.27	42.69	39.82	36.95
44	51.14	48.24	45.65	43.05	40.16	37.27
45	51.55	48.64	46.03	43.42	40.51	37.59
46	51.96	49.03	46.41	43.78	40.85	37.92
47	52.37	49.42	46.78	44.15	41.20	38.24
48	52.78	49.81	47.16	44.51	41.54	38.57
49	53.20	50.20	47.54	44.88	41.89	38.89
50	53.61	50.59	47.92	45.24	42.23	39.22

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 80 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
51	54.02	50.99	48.30	45.61	42.57	39.54
52	54.43	51.38	48.68	45.97	42.92	39.86
53	54.84	51.77	49.05	46.34	43.26	40.19
54	55.26	52.16	49.43	46.70	43.61	40.51
55	55.67	52.55	49.81	47.07	43.95	40.84
56	56.08	52.95	50.19	47.43	44.30	41.16
57	56.49	53.34	50.57	47.80	44.64	41.49
58	56.91	53.73	50.95	48.16	44.99	41.81
59	57.32	54.12	51.32	48.53	45.33	42.14
60	57.73	54.51	51.70	48.89	45.68	42.46
61	58.14	54.91	52.08	49.26	46.02	42.78
62	58.55	55.30	52.46	49.62	46.36	43.11
63	58.97	55.69	52.84	49.99	46.71	43.43
64	59.38	56.08	53.22	50.35	47.05	43.76
65	59.79	56.47	53.59	50.72	47.40	44.08
66	60.20	56.86	53.97	51.08	47.74	44.41
67	60.61	57.26	54.35	51.45	48.09	44.73
68	61.03	57.65	54.73	51.81	48.43	45.05
69	61.44	58.04	55.11	52.18	48.78	45.38
GROUND LINE (10 FEET, 0 INCHES)						
70	61.85	58.43	55.49	52.54	49.12	45.70
71	62.26	58.82	55.86	52.91	49.47	46.03
72	62.68	59.22	56.24	53.27	49.81	46.35
73	63.09	59.61	56.62	53.64	50.16	46.68
74	63.50	60.00	57.00	54.00	50.50	47.00
75	63.91	60.39	57.38	54.36	50.84	47.32
76	64.32	60.78	57.76	54.73	51.19	47.65
77	64.74	61.18	58.14	55.09	51.53	47.97
78	65.15	61.57	58.51	55.46	51.88	48.30
79	65.56	61.96	58.89	55.82	52.22	48.62
80	65.97	62.35	59.27	56.19	52.57	48.95

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 85 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.41	31.39	29.37	27.35	25.34	23.32
2	33.81	31.77	29.75	27.71	25.67	23.63
3	34.22	32.16	30.12	28.06	26.01	23.95
4	34.62	32.54	30.49	28.42	26.34	24.27
5	35.03	32.93	30.87	28.77	26.68	24.58
6	35.43	33.32	31.24	29.13	27.01	24.90
7	35.84	33.70	31.61	29.48	27.35	25.22
8	36.24	34.09	31.99	29.84	27.68	25.53
9	36.65	34.47	32.36	30.19	28.02	25.85
10	37.05	34.86	32.73	30.54	28.35	26.16

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Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

85 FOOT POLE—**con.**

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
11	37.46	35.25	33.11	30.90	28.69	26.48
12	37.86	35.63	33.48	31.25	29.03	26.80
13	38.27	36.02	33.85	31.61	29.36	27.11
14	38.67	36.41	34.23	31.96	29.70	27.43
15	39.08	36.79	34.60	32.32	30.03	27.75
16	39.48	37.18	34.97	32.67	30.37	28.06
17	39.89	37.56	35.35	33.03	30.70	28.38
18	40.29	37.95	35.72	33.38	31.04	28.70
19	40.70	38.34	36.09	33.73	31.37	29.01
20	41.10	38.72	36.47	34.09	31.71	29.33
21	41.51	39.11	36.84	34.44	32.04	29.65
22	41.91	39.49	37.22	34.80	32.38	29.96
23	42.32	39.88	37.59	35.15	32.72	30.28
24	42.72	40.27	37.96	35.51	33.05	30.59
25	43.13	40.65	38.34	35.86	33.39	30.91
26	43.53	41.04	38.71	36.22	33.72	31.23
27	43.94	41.42	39.08	36.57	34.06	31.54
28	44.34	41.81	39.46	36.92	34.39	31.86
29	44.75	42.20	39.83	37.28	34.73	32.18
30	45.15	42.58	40.20	37.63	35.06	32.49
31	45.56	42.97	40.58	37.99	35.40	32.81
32	45.96	43.35	40.95	38.34	35.73	33.13
33	46.37	43.74	41.32	38.70	36.07	33.44
34	46.77	44.13	41.70	39.05	36.41	33.76
35	47.18	44.51	42.07	39.41	36.74	34.08
36	47.58	44.90	42.44	39.76	37.08	34.39
37	47.99	45.28	42.82	40.11	37.41	34.71
38	48.39	45.67	43.19	40.47	37.75	35.03
39	48.80	46.06	43.56	40.82	38.08	35.34
40	49.20	46.44	43.94	41.18	38.42	35.66
41	49.61	46.83	44.31	41.53	38.75	35.97
42	50.01	47.22	44.68	41.89	39.09	36.29
43	50.42	47.60	45.06	42.24	39.42	36.61
44	50.82	47.99	45.43	42.59	39.76	36.92
45	51.23	48.37	45.80	42.95	40.09	37.24
46	51.63	48.76	46.18	43.30	40.43	37.56
47	52.04	49.15	46.55	43.66	40.77	37.87
48	52.44	49.53	46.92	44.01	41.10	38.19
49	52.85	49.92	47.30	44.37	41.44	38.51
50	53.25	50.30	47.67	44.72	41.77	38.82
51	53.66	50.69	48.04	45.08	42.11	39.14
52	54.06	51.08	48.42	45.43	42.44	39.46
53	54.47	51.46	48.79	45.78	42.78	39.77
54	54.87	51.85	49.16	46.14	43.11	40.09
55	55.28	52.23	49.54	46.49	43.45	40.41
56	55.68	52.62	49.91	46.85	43.78	40.72
57	56.09	53.01	50.28	47.20	44.12	41.04
58	56.49	53.39	50.66	47.56	44.46	41.35
59	56.90	53.78	51.03	47.91	44.79	41.67
60	57.30	54.16	51.41	48.27	45.13	41.99

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 85 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
61	57.71	54.55	51.78	48.62	45.46	42.30
62	58.11	54.94	52.15	48.97	45.80	42.62
63	58.52	55.32	52.53	49.33	46.13	42.94
64	58.92	55.71	52.90	49.68	46.47	43.25
65	59.33	56.09	53.27	50.04	46.80	43.57
66	59.73	56.48	53.65	50.39	47.14	43.89
67	60.14	56.87	54.02	50.75	47.47	44.20
68	60.54	57.25	54.39	51.10	47.81	44.52
69	60.95	57.64	54.77	51.46	48.15	44.84
70	61.35	58.03	55.14	51.81	48.48	45.15
71	61.76	58.41	55.51	52.16	48.82	45.47
72	62.16	58.80	55.89	52.52	49.15	45.78
73	62.57	59.18	56.26	52.87	49.49	46.10
74	62.97	59.57	56.63	53.23	49.82	46.42
GROUND LINE (10 FEET, 6 INCHES)						
75	63.38	59.96	57.01	53.58	50.16	46.73
76	63.78	60.34	57.38	53.94	50.49	47.05
77	64.19	60.73	57.75	54.29	50.83	47.37
78	64.59	61.11	58.13	54.65	51.16	47.68
79	65.00	61.50	58.50	55.00	51.50	48.00
80	65.41	61.89	58.87	55.35	51.84	48.32
81	65.81	62.27	59.25	55.71	52.17	48.63
82	66.22	62.66	59.62	56.06	52.51	48.95
83	66.62	63.04	59.99	56.42	52.84	49.27
84	67.03	63.43	60.37	56.77	53.18	49.58
85	67.43	63.82	60.74	57.13	53.51	49.90

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 90 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.40	31.38	29.36	27.35	25.33	23.31
2	33.80	31.76	29.73	27.69	25.67	23.62
3	34.20	32.14	30.09	28.04	26.00	23.93
4	34.60	32.52	30.45	28.38	26.33	24.24
5	34.99	32.90	30.82	28.73	26.67	24.55
6	35.39	33.29	31.18	29.07	27.00	24.86
7	35.79	33.67	31.54	29.42	27.33	25.17
8	36.19	34.05	31.90	29.76	27.67	25.48
9	36.59	34.43	32.27	30.11	28.00	25.79
10	36.99	34.81	32.63	30.45	28.33	26.10
11	37.39	35.19	32.99	30.80	28.67	26.40
12	37.79	35.57	33.36	31.14	29.00	26.71
13	38.18	35.95	33.72	31.49	29.33	27.02
14	38.58	36.33	34.08	31.83	29.67	27.33
15	38.98	36.71	34.45	32.18	30.00	27.64
16	39.38	37.10	34.81	32.52	30.33	27.95
17	39.78	37.48	35.17	32.87	30.67	28.26
18	40.18	37.86	35.54	33.21	31.00	28.57
19	40.58	38.24	35.90	33.56	31.33	28.88
20	40.98	38.62	36.26	33.90	31.67	29.19

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

90 FOOT POLE–con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
21	41.37	39.00	36.62	34.25	32.00	29.50
22	41.77	39.38	36.99	34.60	32.33	29.81
23	42.17	39.76	37.35	34.94	32.67	30.12
24	42.57	40.14	37.71	35.29	33.00	30.43
25	42.97	40.52	38.08	35.63	33.33	30.74
26	43.37	40.90	38.44	35.98	33.67	31.05
27	43.77	41.29	38.80	36.32	34.00	31.36
28	44.17	41.67	39.17	36.67	34.33	31.67
29	44.57	42.05	39.53	37.01	34.67	31.98
30	44.96	42.43	39.89	37.36	35.00	32.29
31	45.36	42.81	40.26	37.70	35.33	32.60
32	45.76	43.19	40.62	38.05	35.67	32.90
33	46.16	43.57	40.98	38.39	36.00	33.21
34	46.56	43.95	41.35	38.74	36.33	33.52
35	46.96	44.33	41.71	39.08	36.67	33.83
36	47.36	44.71	42.07	39.43	37.00	34.14
37	47.76	45.10	42.43	39.77	37.33	34.45
38	48.15	45.48	42.80	40.12	37.67	34.76
39	48.55	45.86	43.16	40.46	38.00	35.07
40	48.95	46.24	43.52	40.81	38.33	35.38
41	49.35	46.62	43.89	41.15	38.67	35.69
42	49.75	47.00	44.25	41.50	39.00	36.00
43	50.15	47.38	44.61	41.85	39.33	36.31
44	50.55	47.76	44.98	42.19	39.67	36.62
45	50.95	48.14	45.34	42.54	40.00	36.93
46	51.35	48.52	45.70	42.88	40.33	37.24
47	51.74	48.90	46.07	43.23	40.67	37.55
48	52.14	49.29	46.43	43.57	41.00	37.86
49	52.54	49.67	46.79	43.92	41.33	38.17
50	52.94	50.05	47.15	44.26	41.67	38.48
51	53.34	50.43	47.52	44.61	42.00	38.79
52	53.74	50.81	47.88	44.95	42.33	39.10
53	54.14	51.19	48.24	45.30	42.67	39.40
54	54.54	51.57	48.61	45.64	43.00	39.71
55	54.93	51.95	48.97	45.99	43.33	40.02
56	55.33	52.33	49.33	46.33	43.67	40.33
57	55.73	52.71	49.70	46.68	44.00	40.64
58	56.13	53.10	50.06	47.02	44.33	40.95
59	56.53	53.48	50.42	47.37	44.67	41.26
60	56.93	53.86	50.79	47.71	45.00	41.57
61	57.33	54.24	51.15	48.06	45.33	41.88
62	57.73	54.62	51.51	48.40	45.67	42.19
63	58.12	55.00	51.87	48.75	46.00	42.50
64	58.52	55.38	52.24	49.10	46.33	42.81
65	58.92	55.76	52.60	49.44	46.67	43.12
66	59.32	56.14	52.96	49.79	47.00	43.43
67	59.72	56.52	53.33	50.13	47.33	43.74
68	60.12	56.90	53.69	50.48	47.67	44.05
69	60.52	57.29	54.05	50.82	48.00	44.36
70	60.92	57.67	54.42	51.17	48.33	44.67

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

90 FOOT POLE—con.

SOUTHERN YELLOW PINE AND DOUGLAS FIR

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
71	61.32	58.05	54.78	51.51	48.67	44.98
72	61.71	58.43	55.14	51.86	49.00	45.29
73	62.11	58.81	55.51	52.20	49.33	45.60
74	62.51	59.19	55.87	52.55	49.67	45.90
75	62.91	59.57	56.23	52.89	50.00	46.21
76	63.31	59.95	56.60	53.24	50.33	46.52
77	63.71	60.33	56.96	53.58	50.67	46.83
78	64.11	60.71	57.32	53.93	51.00	47.14
GROUND LINE (11 FEET, 0 INCHES)						
79	64.51	61.10	57.68	54.27	51.33	47.45
80	64.90	61.48	58.05	54.62	51.67	47.76
81	65.30	61.86	58.41	54.96	52.00	48.07
82	65.70	62.24	58.77	55.31	52.33	48.38
83	66.10	62.62	59.14	55.65	52.67	48.69
84	66.50	63.00	59.50	56.00	53.00	49.00
85	66.90	63.38	59.86	56.35	53.33	49.31
86	67.30	63.76	60.23	56.69	53.67	49.62
87	67.70	64.14	60.59	57.04	54.00	49.93
88	68.10	64.52	60.95	57.38	54.33	50.24
89	68.49	64.90	61.32	57.73	54.67	50.55
90	68.89	65.29	61.68	58.07	55.00	50.86

95 FOOT POLE

SOUTHERN YELLOW PINE AND DOUGLAS FIR

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.39	31.38	29.36	27.34	25.33
2	33.78	31.75	29.72	27.67	25.65
3	34.16	32.13	30.08	28.01	25.98
4	34.55	32.51	30.44	28.35	26.30
5	34.94	32.88	30.80	28.69	26.63
6	35.33	33.26	31.16	29.02	26.96
7	35.71	33.63	31.52	29.36	27.28
8	36.10	34.01	31.88	29.70	27.61
9	36.49	34.39	32.24	30.03	27.93
10	36.88	34.76	32.60	30.37	28.26
11	37.26	35.14	32.96	30.71	28.58
12	37.65	35.52	33.31	31.04	28.91
13	38.04	35.89	33.67	31.38	29.24
14	38.43	36.27	34.03	31.72	29.56
15	38.81	36.65	34.39	32.06	29.89
16	39.20	37.02	34.75	32.39	30.21
17	39.59	37.40	35.11	32.73	30.54
18	39.98	37.78	35.47	33.07	30.87
19	40.37	38.15	35.83	33.40	31.19
20	40.75	38.53	36.19	33.74	31.52

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Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR 95 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
21	41.14	38.90	36.55	34.08	31.84
22	41.53	39.28	36.91	34.42	32.17
23	41.92	39.66	37.27	34.75	32.49
24	42.30	40.03	37.63	35.09	32.82
25	42.69	40.41	37.99	35.43	33.15
26	43.08	40.79	38.35	35.76	33.47
27	43.47	41.16	38.71	36.10	33.80
28	43.85	41.54	39.07	36.44	34.12
29	44.24	41.92	39.43	36.78	34.45
30	44.63	42.29	39.79	37.11	34.78
31	45.02	42.67	40.15	37.45	35.10
32	45.40	43.04	40.51	37.79	35.43
33	45.79	43.42	40.87	38.12	35.75
34	46.18	43.80	41.22	38.46	36.08
35	46.57	44.17	41.58	38.80	36.40
36	46.96	44.55	41.94	39.13	36.73
37	47.34	44.93	42.30	39.47	37.06
38	47.73	45.30	42.66	39.81	37.38
39	48.12	45.68	43.02	40.15	37.71
40	48.51	46.06	43.38	40.48	38.03
41	48.89	46.43	43.74	40.82	38.36
42	49.28	46.81	44.10	41.16	38.69
43	49.67	47.19	44.46	41.49	39.01
44	50.06	47.56	44.82	41.83	39.34
45	50.44	47.94	45.18	42.17	39.66
46	50.83	48.31	45.54	42.51	39.99
47	51.22	48.69	45.90	42.84	40.31
48	51.61	49.07	46.26	43.18	40.64
49	51.99	49.44	46.62	43.52	40.97
50	52.38	49.82	46.98	43.85	41.29
51	52.77	50.20	47.34	44.19	41.62
52	53.16	50.57	47.70	44.53	41.94
53	53.54	50.95	48.06	44.87	42.27
54	53.93	51.33	48.42	45.20	42.60
55	54.32	51.70	48.78	45.54	42.92
56	54.71	52.08	49.13	45.88	43.25
57	55.10	52.46	49.49	46.21	43.57
58	55.48	52.83	49.85	46.55	43.90
59	55.87	53.21	50.21	46.89	44.22
60	56.26	53.58	50.57	47.22	44.55
61	56.65	53.96	50.93	47.56	44.88
62	57.03	54.34	51.29	47.90	45.20
63	57.42	54.71	51.65	48.24	45.53
64	57.81	55.09	52.01	48.57	45.85
65	58.20	55.47	52.37	48.91	46.18
66	58.58	55.84	52.73	49.25	46.51
67	58.97	56.22	53.09	49.58	46.83
68	59.36	56.60	53.45	49.92	47.16
69	59.75	56.97	53.81	50.26	47.48
70	60.13	57.35	54.17	50.60	47.81

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

95 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
71	60.52	57.72	54.53	50.93	48.13
72	60.91	58.10	54.89	51.27	48.46
73	61.30	58.48	55.25	51.61	48.79
74	61.69	58.85	55.61	51.94	49.11
75	62.07	59.23	55.97	52.28	49.44
76	62.46	59.61	56.33	52.62	49.76
77	62.85	59.98	56.69	52.96	50.09
78	63.24	60.36	57.04	53.29	50.42
79	63.62	60.74	57.40	53.63	50.74
80	64.01	61.11	57.76	53.97	51.07
81	64.40	61.49	58.12	54.30	51.39
82	64.79	61.87	58.48	54.64	51.72
83	65.17	62.24	58.84	54.98	52.04
------------GROUND LINE (11 FEET, 0 INCHES)---------------					
84	65.56	62.62	59.20	55.31	52.37
85	65.95	62.99	59.56	55.65	52.70
86	66.34	63.37	59.92	55.99	53.02
87	66.72	63.75	60.28	56.33	53.35
88	67.11	64.12	60.64	56.66	53.67
89	67.50	64.50	61.00	57.00	54.00
90	67.89	64.88	61.36	57.34	54.33
91	68.28	65.25	61.72	57.67	54.65
92	68.66	65.63	62.08	58.01	54.98
93	69.05	66.01	62.44	58.35	55.30
94	69.44	66.38	62.80	58.69	55.63
95	69.83	66.76	63.16	59.02	55.96

SOUTHERN YELLOW PINE AND DOUGLAS FIR

100 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.38	31.37	29.35	27.34	25.32
2	33.77	31.73	29.70	27.67	25.64
3	34.15	32.10	30.05	28.01	25.96
4	34.53	32.47	30.40	28.34	26.28
5	34.91	32.84	30.76	28.68	26.60
6	35.30	33.20	31.11	29.01	26.91
7	35.68	33.57	31.46	29.35	27.23
8	36.06	33.94	31.81	29.68	27.55
9	36.45	34.30	32.16	30.02	27.87
10	36.83	34.67	32.51	30.35	28.19
11	37.21	35.04	32.86	30.69	28.51
12	37.60	35.40	33.21	31.02	28.83
13	37.98	35.77	33.56	31.36	29.15
14	38.36	36.14	33.91	31.69	29.47
15	38.74	36.51	34.27	32.03	29.79
16	39.13	36.87	34.62	32.36	30.11
17	39.51	37.24	34.97	32.70	30.43
18	39.89	37.61	35.32	33.03	30.74
19	40.28	37.97	35.67	33.37	31.06
20	40.66	38.34	36.02	33.70	31.38

Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR 100 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
21	41.04	38.71	36.37	34.04	31.70
22	41.43	39.07	36.72	34.37	32.02
23	41.81	39.44	37.07	34.71	32.34
24	42.19	39.81	37.43	35.04	32.66
25	42.57	40.18	37.78	35.38	32.98
26	42.96	40.54	38.13	35.71	33.30
27	43.34	40.91	38.48	36.05	33.62
28	43.72	41.28	38.83	36.38	33.94
29	44.11	41.64	39.18	36.72	34.26
30	44.49	42.01	39.53	37.05	34.57
31	44.87	42.38	39.88	37.39	34.89
32	45.26	42.74	40.23	37.72	35.21
33	45.64	43.11	40.59	38.06	35.53
34	46.02	43.48	40.94	38.39	35.85
35	46.40	43.85	41.29	38.73	36.17
36	46.79	44.21	41.64	39.06	36.49
37	47.17	44.58	41.99	39.40	36.81
38	47.55	44.95	42.34	39.73	37.13
39	47.94	45.31	42.69	40.07	37.45
40	48.32	45.68	43.04	40.40	37.77
41	48.70	46.05	43.39	40.74	38.09
42	49.09	46.41	43.74	41.07	38.40
43	49.47	46.78	44.10	41.41	38.72
44	49.85	47.15	44.45	41.74	39.04
45	50.23	47.52	44.80	42.08	39.36
46	50.62	47.88	45.15	42.41	39.68
47	51.00	48.25	45.50	42.75	40.00
48	51.38	48.62	45.85	43.09	40.32
49	51.77	48.98	46.20	43.42	40.64
50	52.15	49.35	46.55	43.76	40.96
51	52.53	49.72	46.90	44.09	41.28
52	52.91	50.09	47.26	44.43	41.60
53	53.30	50.45	47.61	44.76	41.91
54	53.68	50.82	47.96	45.10	42.23
55	54.06	51.19	48.31	45.43	42.55
56	54.45	51.55	48.66	45.77	42.87
57	54.83	51.92	49.01	46.10	43.19
58	55.21	52.29	49.36	46.44	43.51
59	55.60	52.65	49.71	46.77	43.83
60	55.98	53.02	50.06	47.11	44.15
61	56.36	53.39	50.41	47.44	44.47
62	56.74	53.76	50.77	47.78	44.79
63	57.13	54.12	51.12	48.11	45.11
64	57.51	54.49	51.47	48.45	45.43
65	57.89	54.86	51.82	48.78	45.74
66	58.28	55.22	52.17	49.12	46.06
67	58.66	55.59	52.52	49.45	46.38
68	59.04	55.96	52.87	49.79	46.70
69	59.43	56.32	53.22	50.12	47.02
70	59.81	56.69	53.57	50.46	47.34

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR 100 FOOT POLE**—con.**

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
71	60.19	57.06	53.93	50.79	47.66
72	60.57	57.43	54.28	51.13	47.98
73	60.96	57.79	54.63	51.46	48.30
74	61.34	58.16	54.98	51.80	48.62
75	61.72	58.53	55.33	52.13	48.94
76	62.11	58.89	55.68	52.47	49.26
77	62.49	59.26	56.03	52.80	49.57
78	62.87	59.63	56.38	53.14	49.89
79	63.26	59.99	56.73	53.47	50.21
80	63.64	60.36	57.09	53.81	50.53
81	64.02	60.73	57.44	54.14	50.85
82	64.40	61.10	57.79	54.48	51.17
83	64.79	61.46	58.14	54.81	51.49
84	65.17	61.83	58.49	55.15	51.81
85	65.55	62.20	58.84	55.48	52.13
86	65.94	62.56	59.19	55.82	52.45
87	66.32	62.93	59.54	56.15	52.77
88	66.70	63.30	59.89	56.49	53.09
------------GROUND LINE (11 FEET, 0 INCHES)--------------					
89	67.09	63.66	60.24	56.82	53.40
90	67.47	64.03	60.60	57.16	53.72
91	67.85	64.40	60.95	57.49	54.04
92	68.23	64.77	61.30	57.83	54.36
93	68.62	65.13	61.65	58.16	54.68
94	69.00	65.50	62.00	58.50	55.00
95	69.38	65.87	62.35	58.84	55.32
96	69.77	66.23	62.70	59.17	55.64
97	70.15	66.60	63.05	59.51	55.96
98	70.53	66.97	63.40	59.84	56.28
99	70.91	67.34	63.76	60.18	56.60
100	71.30	67.70	64.11	60.51	56.91

SOUTHERN YELLOW PINE AND DOUGLAS FIR 105 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.38	31.36	29.34	27.33	25.31
2	33.76	31.73	29.69	27.66	25.63
3	34.14	32.09	30.03	27.98	25.94
4	34.52	32.45	30.37	28.31	26.25
5	34.89	32.82	30.72	28.64	26.57
6	35.27	33.18	31.06	28.97	26.88
7	35.65	33.55	31.40	29.30	27.19
8	36.03	33.91	31.75	29.63	27.51
9	36.41	34.27	32.09	29.95	27.82
10	36.79	34.64	32.43	30.28	28.13

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR					105 FOOT POLE—con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
11	37.17	35.00	32.78	30.61	28.44
12	37.55	35.36	33.12	30.94	28.76
13	37.92	35.73	33.46	31.27	29.07
14	38.30	36.09	33.81	31.60	29.38
15	38.68	36.45	34.15	31.92	29.70
16	39.06	36.82	34.49	32.25	30.01
17	39.44	37.18	34.84	32.58	30.32
18	39.82	37.55	35.18	32.91	30.64
19	40.20	37.91	35.53	33.24	30.95
20	40.58	38.27	35.87	33.57	31.26
21	40.95	38.64	36.21	33.89	31.58
22	41.33	39.00	36.56	34.22	31.89
23	41.71	39.36	36.90	34.55	32.20
24	42.09	39.73	37.24	34.88	32.52
25	42.47	40.09	37.59	35.21	32.83
26	42.85	40.45	37.93	35.54	33.14
27	43.23	40.82	38.27	35.86	33.45
28	43.61	41.18	38.62	36.19	33.77
29	43.98	41.55	38.96	36.52	34.08
30	44.36	41.91	39.30	36.85	34.39
31	44.74	42.27	39.65	37.18	34.71
32	45.12	42.64	39.99	37.51	35.02
33	45.50	43.00	40.33	37.83	35.33
34	45.88	43.36	40.68	38.16	35.65
35	46.26	43.73	41.02	38.49	35.96
36	46.64	44.09	41.36	38.82	36.27
37	47.02	44.45	41.71	39.15	36.59
38	47.39	44.82	42.05	39.47	36.90
39	47.77	45.18	42.39	39.80	37.21
40	48.15	45.55	42.74	40.13	37.53
41	48.53	45.91	43.08	40.46	37.84
42	48.91	46.27	43.42	40.79	38.15
43	49.29	46.64	43.77	41.12	38.46
44	49.67	47.00	44.11	41.44	38.78
45	50.05	47.36	44.45	41.77	39.09
46	50.42	47.73	44.80	42.10	39.40
47	50.80	48.09	45.14	42.43	39.72
48	51.18	48.45	45.48	42.76	40.03
49	51.56	48.82	45.83	43.09	40.34
50	51.94	49.18	46.17	43.41	40.66
51	52.32	49.55	46.52	43.74	40.97
52	52.70	49.91	46.86	44.07	41.28
53	53.08	50.27	47.20	44.40	41.60
54	53.45	50.64	47.55	44.73	41.91
55	53.83	51.00	47.89	45.06	42.22
56	54.21	51.36	48.23	45.38	42.54
57	54.59	51.73	48.58	45.71	42.85
58	54.97	52.09	48.92	46.04	43.16
59	55.35	52.45	49.26	46.37	43.47
60	55.73	52.82	49.61	46.70	43.79

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR					105 FOOT POLE–con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
61	56.11	53.18	49.95	47.03	44.10
62	56.48	53.55	50.29	47.35	44.41
63	56.86	53.91	50.64	47.68	44.73
64	57.24	54.27	50.98	48.01	45.04
65	57.62	54.64	51.32	48.34	45.35
66	58.00	55.00	51.67	48.67	45.67
67	58.38	55.36	52.01	48.99	45.98
68	58.76	55.73	52.35	49.32	46.29
69	59.14	56.09	52.70	49.65	46.61
70	59.52	56.45	53.04	49.98	46.92
71	59.89	56.82	53.38	50.31	47.23
72	60.27	57.18	53.73	50.64	47.55
73	60.65	57.55	54.07	50.96	47.86
74	61.03	57.91	54.41	51.29	48:17
75	61.41	58.27	54.76	51.62	48.48
76	61.79	58.64	55.10	51.95	48.80
77	62.17	59.00	55.44	52.28	49.11
78	62.55	59.36	55.79	52.61	49.42
79	62.92	59.73	56.13	52.93	49.74
80	63.30	60.09	56.47	53.26	50.05
81	63.68	60.45	56.82	53.59	50.36
82	64.06	60.82	57.16	53.92	50.68
83	64.44	61.18	57.51	54.25	50.99
84	64.82	61.55	57.85	54.58	51.30
85	65.20	61.91	58.19	54.90	51.62
86	65.58	62.27	58.54	55.23	51.93
87	65.95	62.64	58.88	55.56	52.24
88	66.33	63.00	59.22	55.89	52.56
89	66.71	63.36	59.57	56.22	52.87
90	67.09	63.73	59.91	56.55	53.18
91	67.47	64.09	60.25	56.87	53.49
92	67.85	64.45	60.60	57.20	53.81
-------------GROUND LINE (12 FEET, 0 INCHES)--------------					
93	68.23	64.82	60.94	57.53	54.12
94	68.61	65.18	61.28	57.86	54.43
95	68.98	65.55	61.63	58.19	54.75
96	69.36	65.91	61.97	58.52	55.06
97	69.74	66.27	62.31	58.84	55.37
98	70.12	66.64	62.66	59.17	55.69
99	70.50	67.00	63.00	59.50	56.00
100	70.88	67.36	63.34	59.83	56.31
101	71.26	67.73	63.69	60.16	56.63
102	71.64	68.09	64.03	60.48	56.94
103	72.02	68.45	64.37	60.81	57.25
104	72.39	68.82	64.72	61.14	57.57
105	72.77	69.18	65.06	61.47	57.88

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

110 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.37	31.36	29.34	27.32	25.31
2	33.74	31.71	29.68	27.64	25.62
3	34.11	32.07	30.02	27.97	25.92
4	34.48	32.42	30.37	28.29	26.23
5	34.85	32.78	30.71	28.61	26.54
6	35.22	33.13	31.05	28.93	26.85
7	35.59	33.49	31.39	29.25	27.15
8	35.96	33.85	31.73	29.58	27.46
9	36.33	34.20	32.07	29.90	27.77
10	36.70	34.56	32.41	30.22	28.08
11	37.07	34.91	32.75	30.54	28.38
12	37.44	35.27	33.10	30.87	28.69
13	37.81	35.62	33.44	31.19	29.00
14	38.18	35.98	33.78	31.51	29.31
15	38.55	36.34	34.12	31.83	29.62
16	38.92	36.69	34.46	32.15	29.92
17	39.29	37.05	34.80	32.48	30.23
18	39.66	37.40	35.14	32.80	30.54
19	40.03	37.76	35.49	33.12	30.85
20	40.40	38.12	35.83	33.44	31.15
21	40.77	38.47	36.17	33.76	31.46
22	41.14	38.83	36.51	34.09	31.77
23	41.51	39.18	36.85	34.41	32.08
24	41.88	39.54	37.19	34.73	32.38
25	42.25	39.89	37.53	35.05	32.69
26	42.62	40.25	37.87	35.37	33.00
27	43.00	40.61	38.22	35.70	33.31
28	43.37	40.96	38.56	36.02	33.62
29	43.74	41.32	38.90	36.34	33.92
30	44.11	41.67	39.24	36.66	34.23
31	44.48	42.03	39.58	36.99	34.54
32	44.85	42.38	39.92	37.31	34.85
33	45.22	42.74	40.26	37.63	35.15
34	45.59	43.10	40.61	37.95	35.46
35	45.96	43.45	40.95	38.27	35.77
36	46.33	43.81	41.29	38.60	36.08
37	46.70	44.16	41.63	38.92	36.38
38	47.07	44.52	41.97	39.24	36.69
39	47.44	44.87	42.31	39.56	37.00
40	47.81	45.23	42.65	39.88	37.31
41	48.18	45.59	43.00	40.21	37.62
42	48.55	45.94	43.34	40.53	37.92
43	48.92	46.30	43.68	40.85	38.23
44	49.29	46.65	44.02	41.17	38.54
45	49.66	47.01	44.36	41.50	38.85
46	50.03	47.37	44.70	41.82	39.15
47	50.40	47.72	45.04	42.14	39.46
48	50.77	48.08	45.38	42.46	39.77
49	51.14	48.43	45.73	42.78	40.08
50	51.51	48.79	46.07	43.11	40.38

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR					110 FOOT POLE–**con.**
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
51	51.88	49.14	46.41	43.43	40.69
52	52.25	49.50	46.75	43.75	41.00
53	52.62	49 86	47.09	44.07	41.31
54	52.99	50.21	47.43	44.39	41.62
55	53.36	50.57	47.77	44.72	41.92
56	53.73	50.92	48.12	45.04	42.23
57	54.10	51.28	48.46	45.36	42.54
58	54.47	51.63	48.80	45.68	42.85
59	54.84	51.99	49.14	46.00	43.15
60	55.21	52.35	49.48	46.33	43.46
61	55.58	52.70	49.82	46.65	43.77
62	55.95	53.06	50.16	46.97	44.08
63	56.32	53.41	50.50	47.29	44.38
64	56.69	53.77	50.85	47.62	44.69
65	57.06	54.12	51.19	47.94	45.00
66	57.43	54.48	51.53	48.26	45.31
67	57.80	54.84	51.87	48.58	45.62
68	58.17	55.19	52.21	48.90	45.92
69	58.54	55.55	52.55	49.23	46.23
70	58.91	55.90	52.89	49.55	46.54
71	59.28	56.26	53.24	49.87	46.85
72	59.65	56.62	53.58	50.19	47.15
73	60.02	56.97	53.92	50.51	47.46
74	60.39	57.33	54.26	50.84	47.77
75	60.76	57.68	54.60	51.16	48.08
76	61.13	58.04	54.94	51.48	48.38
77	61.50	58.39	55.28	51.80	48.69
78	61.87	58.75	55.62	52.12	49.00
79	62.25	59.11	55.97	52.45	49.31
80	62.62	59.46	56.31	52.77	49.62
81	62.99	59.82	56.65	53.09	49.92
82	63.36	60.17	56.99	53.41	50.23
83	63.73	60.53	57.33	53.74	50.54
84	64.10	60.88	57.67	54.06	50.85
85	64.47	61.24	58.01	54.38	51.15
86	64.84	61.60	58.36	54.70	51.46
87	65.21	61.95	58.70	55.02	51.77
88	65.58	62.31	59.04	55.35	52.08
89	65.95	62.66	59.38	55.67	52.38
90	66.32	63.02	59.72	55.99	52.69
91	66.69	63.37	60.06	56.31	53.00
92	67.06	63.73	60.40	56.63	53.31
93	67.43	64.09	60.75	56.96	53.62
94	67.80	64.44	61.09	57.28	53.92
95	68.17	64.80	61.43	57.60	54.23
96	68.54	65.15	61.77	57.92	54.54
97	68.91	65.51	62.11	58.25	54.85
-------------GROUND LINE (12 FEET, 0 INCHES)--------------					
98	69.28	65.87	62.45	58.57	55.15
99	69.65	66.22	62.79	58.89	55.46
100	70.02	66.58	63.13	59.21	55.77

Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

110 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
101	70.39	66.93	63.48	59.53	56.08
102	70.76	67.29	63.82	59.86	56.38
103	71.13	67.64	64.16	60.18	56.69
104	71.50	68.00	64.50	60.50	57.00
105	71.87	68.36	64.84	60.82	57.31
106	72.24	68.71	65.18	61.14	57.62
107	72.61	69.07	65.52	61.47	57.92
108	72.98	69.42	65.87	61.79	58.23
109	73.35	69.78	66.21	62.11	58.54
110	73.72	70.13	66.55	62.43	58.85

SOUTHERN YELLOW PINE AND DOUGLAS FIR

115 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.36	31.35	29.33	27.32	25.30
2	33.72	31.70	29.67	27.63	25.61
3	34.09	32.05	30.00	27.95	25.91
4	34.45	32.39	30.34	28.27	26.21
5	34.81	32.74	30.67	28.58	26.51
6	35.17	33.09	31.01	28.90	26.82
7	35.54	33.44	31.34	29.22	27.12
8	35.90	33.79	31.68	29.53	27.42
9	36.26	34.14	32.01	29.85	27.72
10	36.62	34.49	32.35	30.17	28.03
11	36.99	34.83	32.68	30.48	28.33
12	37.35	35.18	33.02	30.80	28.63
13	37.71	35.53	33.35	31.11	28.94
14	38.07	35.88	33.69	31.43	29.24
15	38.44	36.23	34.02	31.75	29.54
16	38.80	36.58	34.36	32.06	29.84
17	39.16	36.93	34.69	32.38	30.15
18	39.52	37.28	35.03	32.70	30.45
19	39.89	37.62	35.36	33.01	30.75
20	40.25	37.97	35.70	33.33	31.06
21	40.61	38.32	36.03	33.65	31.36
22	40.97	38.67	36.37	33.96	31.66
23	41.33	39.02	36.70	34.28	31.96
24	41.70	39.37	37.04	34.60	32.27
25	42.06	39.72	37.37	34.91	32.57
26	42.42	40.06	37.71	35.23	32.87
27	42.78	40.41	38.04	35.55	33.17
28	43.15	40.76	38.38	35.86	33.48
29	43.51	41.11	38.71	36.18	33.78
30	43.87	41.46	39.05	36.50	34.08

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR					115 FOOT POLE—con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
31	44.23	41.81	39.38	36.81	34.39
32	44.60	42.16	39.72	37.13	34.69
33	44.96	42.50	40.05	37.44	34.99
34	45.32	42.85	40.39	37.76	35.29
35	45.68	43.20	40.72	38.08	35.60
36	46.05	43.55	41.06	38.39	35.90
37	46.41	43.90	41.39	38.71	36.20
38	46.77	44.25	41.72	39.03	36.50
39	47.13	44.60	42.06	39.34	36.81
40	47.50	44.94	42.39	39.66	37.11
41	47.86	45.29	42.73	39.98	37.41
42	48.22	45.64	43.06	40.29	37.72
43	48.58	45.99	43.40	40.61	38.02
44	48.94	46.34	43.73	40.93	38.32
45	49.31	46.69	44.07	41.24	38.62
46	49.67	47.04	44.40	41.56	38.93
47	50.03	47.39	44.74	41.88	39.23
48	50.39	47.73	45.07	42.19	39.53
49	50.76	48.08	45.41	42.51	39.83
50	51.12	48.43	45.74	42.83	40.14
51	51.48	48.78	46.08	43.14	40.44
52	51.84	49.13	46.41	43.46	40.74
53	52.21	49.48	46.75	43.78	41.05
54	52.57	49.83	47.08	44.09	41.35
55	52.93	50.17	47.42	44.41	41.65
56	53.29	50.52	47.75	44.72	41.95
57	53.66	50.87	48.09	45.04	42.26
58	54.02	51.22	48.42	45.36	42.56
59	54.38	51.57	48.76	45.67	42.86
60	54.74	51.92	49.09	45.99	43.17
61	55.11	52.27	49.43	46.31	43.47
62	55.47	52.61	49.76	46.62	43.77
63	55.83	52.96	50.10	46.94	44.07
64	56.19	53.31	50.43	47.26	44.38
65	56.56	53.66	50.77	47.57	44.68
66	56.92	54.01	51.10	47.89	44.98
67	57.28	54.36	51.44	48.21	45.28
68	57.64	54.71	51.77	48.52	45.59
69	58.00	55.06	52.11	48.84	45.89
70	58.37	55.40	52.44	49.16	46.19
71	58.73	55.75	52.78	49.47	46.50
72	59.09	56.10	53.11	49.79	46.80
73	59.45	56.45	53.44	50.11	47.10
74	59.82	56.80	53.78	50.42	47.40
75	60.18	57.15	54.11	50.74	47.71
76	60.54	57.50	54.45	51.06	48.01
77	60.90	57.84	54.78	51.37	48.31
78	61.27	58.19	55.12	51.69	48.61
79	61.63	58.54	55.45	52.00	48.92
80	61.99	58.89	55.79	52.32	49.22

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Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

115 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
81	62.35	59.24	56.12	52.64	49.52
82	62.72	59.59	56.46	52.95	49.83
83	63.08	59.94	56.79	53.27	50.13
84	63.44	60.28	57.13	53.59	50.43
85	63.80	60.63	57.46	53.90	50.73
86	64.17	60.98	57.80	54.22	51.04
87	64.53	61.33	58.13	54.54	51.34
88	64.89	61.68	58.47	54.85	51.64
89	65.25	62.03	58.80	55.17	51.94
90	65.61	62.38	59.14	55.49	52.25
91	65.98	62.72	59.47	55.80	52.55
92	66.34	63.07	59.81	56.12	52.85
93	66.70	63.42	60.14	56.44	53.16
94	67.06	63.77	60.48	56.75	53.46
95	67.43	64.12	60.81	57.07	53.76
96	67.79	64.47	61.15	57.39	54.06
97	68.15	64.82	61.48	57.70	54.37
98	68.51	65.17	61.82	58.02	54.67
99	68.88	65.51	62.15	58.33	54.97
100	69.24	65.86	62.49	58.65	55.28
101	69.60	66.21	62.82	58.97	55.58
102	69.96	66.56	63.16	59.28	55.88
------------GROUND LINE (12 FEET, 0 INCHES)---------------					
103	70.33	66.91	63.49	59.60	56.18
104	70.69	67.26	63.83	59.92	56.49
105	71.05	67.61	64.16	60.23	56.79
106	71.41	67.95	64.50	60.55	57.09
107	71.78	68.30	64.83	60.87	57.39
108	72.14	68.65	65.17	61.18	57.70
109	72.50	69.00	65.50	61.50	58.00
110	72.86	69.35	65.83	61.82	58.30
111	73.22	69.70	66.17	62.13	58.61
112	73.59	70.05	66.50	62.45	58.91
113	73.95	70.39	66.84	62.77	59.21
114	74.31	70.74	67.17	63.08	59.51
115	74.67	71.09	67.51	63.40	59.82

SOUTHERN YELLOW PINE AND DOUGLAS FIR

120 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.36	31.34	29.33	27.31	25.30
2	33.72	31.68	29.66	27.62	25.60
3	34.08	32.03	29.99	27.93	25.89
4	34.44	32.37	30.32	28.25	26.19
5	34.80	32.71	30.64	28.56	26.49
6	35.16	33.05	30.97	28.87	26.79
7	35.52	33.39	31.30	29.18	27.09
8	35.88	33.74	31.63	29.49	27.39
9	36.24	34.08	31.96	29.80	27.68
10	36.60	34.42	32.29	30.11	27.98

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR 120 FOOT POLE–con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
11	36.96	34.76	32.62	30.43	28.28
12	37.32	35.11	32.95	30.74	28.58
13	37.68	35.45	33.28	31.05	28.88
14	38.04	35.79	33.61	31.36	29.18
15	38.39	36.13	33.93	31.67	29.47
16	38.75	36.47	34.26	31.98	29.77
17	39.11	36.82	34.59	32.29	30.07
18	39.47	37.16	34.92	32.61	30.37
19	39.83	37.50	35.25	32.92	30.67
20	40.19	37.84	35.58	33.23	30.96
21	40.55	38.18	35.91	33.54	31.26
22	40.91	38.53	36.24	33.85	31.56
23	41.27	38.87	36.57	34.16	31.86
24	41.63	39.21	36.89	34.47	32.16
25	41.99	39.55	37.22	34.79	32.46
26	42.35	39.89	37.55	35.10	32.75
27	42.71	40.24	37.88	35.41	33.05
28	43.07	40.58	38.21	35.72	33.35
29	43.43	40.92	38.54	36.03	33.65
30	43.79	41.26	38.87	36.34	33.95
31	44.15	41.61	39.20	36.65	34.25
32	44.51	41.95	39.53	36.96	34.54
33	44.87	42.29	39.86	37.28	34.84
34	45.23	42.63	40.18	37.59	35.14
35	45.59	42.97	40.51	37.90	35.44
36	45.95	43.32	40.84	38.21	35.74
37	46.31	43.66	41.17	38.52	36.04
38	46.67	44.00	41.50	38.83	36.33
39	47.03	44.34	41.83	39.14	36.63
40	47.39	44.68	42.16	39.46	36.93
41	47.75	45.03	42.49	39.77	37.23
42	48.11	45.37	42.82	40.08	37.53
43	48.46	45.71	43.14	40.39	37.82
44	48.82	46.05	43.47	40.70	38.12
45	49.18	46.39	43.80	41.01	38.42
46	49.54	46.74	44.13	41.32	38.72
47	49.90	47.08	44.46	41.64	39.02
48	50.26	47.42	44.79	41.95	39.32
49	50.62	47.76	45.12	42.26	39.61
50	50.98	48.11	45.45	42.57	39.91
51	51.34	48.45	45.78	42.88	40.21
52	51.70	48.79	46.11	43.19	40.51
53	52.06	49.13	46.43	43.50	40.81
54	52.42	49.47	46.76	43.82	41.11
55	52.78	49.82	47.09	44.13	41.40
56	53.14	50.16	47.42	44.44	41.70
57	53.50	50.50	47.75	44.75	42.00
58	53.86	50.84	48.08	45.06	42.30
59	54.22	51.18	48.41	45.37	42.60
60	54.58	51.53	48.74	45.68	42.89

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Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR

120 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
61	54.94	51.87	49.07	46.00	43.19
62	55.30	52.21	49.39	46.31	43.49
63	55.66	52.55	49.72	46.62	43.79
64	56.02	52.89	50.05	46.93	44.09
65	56.38	53.24	50.38	47.24	44.39
66	56.74	53.58	50.71	47.55	44.68
67	57.10	53.92	51.04	47.86	44.98
68	57.46	54.26	51.37	48.18	45.28
69	57.82	54.61	51.70	48.49	45.58
70	58.18	54.95	52.03	48.80	45.88
71	58.54	55.29	52.36	49.11	46.18
72	58.89	55.63	52.68	49.42	46.47
73	59.25	55.97	53.01	49.73	46.77
74	59.61	56.32	53.34	50.04	47.07
75	59.97	56.66	53.67	50.36	47.37
76	60.33	57.00	54.00	50.67	47.67
77	60.69	57.34	54.33	50.98	47.96
78	61.05	57.68	54.66	51.29	48.26
79	61.41	58.03	54.99	51.60	48.56
80	61.77	58.37	55.32	51.91	48.86
81	62.13	58.71	55.64	52.22	49.16
82	62.49	59.05	55.97	52.54	49.46
83	62.85	59.39	56.30	52.85	49.75
84	63.21	59.74	56.63	53.16	50.05
85	63.57	60.08	56.96	53.47	50.35
86	63.93	60.42	57.29	53.78	50.65
87	64.29	60.76	57.62	54.09	50.95
88	64.65	61.11	57.95	54.40	51.25
89	65.01	61.45	58.28	54.71	51.54
90	65.37	61.79	58.61	55.03	51.84
91	65.73	62.13	58.93	55.34	52.14
92	66.09	62.47	59.26	55.65	52.44
93	66.45	62.82	59.59	55.96	52.74
94	66.81	63.16	59.92	56.27	53.04
95	67.17	63.50	60.25	56.58	53.33
96	67.53	63.84	60.58	56.89	53.63
97	67.89	64.18	60.91	57.21	53.93
98	68.25	64.53	61.24	57.52	54.23
99	68.61	64.87	61.57	57.83	54.53
100	68.96	65.21	61.89	58.14	54.82
101	69.32	65.55	62.22	58.45	55.12
102	69.68	65.89	62.55	58.76	55.42
103	70.04	66.24	62.88	59.07	55.72
104	70.40	66.58	63.21	59.39	56.02
105	70.76	66.92	63.54	59.70	56.32
106	71.12	67.26	63.87	60.01	56.61
107	71.48	67.61	64.20	60.32	56.91
-------------GROUND LINE (12 FEET. 0 INCHES)---------------					
108	71.84	67.95	64.53	60.63	57.21
109	72.20	68.29	64.86	60.94	57.51
110	72.56	68.63	65.18	61.25	57.81

Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 120 FOOT POLE—con.

DISTANCE FROM TOP /FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
111	72.92	68.97	65.51	61.57	58.11
112	73.28	69.32	65.84	61.88	58.40
113	73.64	69.66	66.17	62.19	58.70
114	74.00	70.00	66.50	62.50	59.00
115	74.36	70.34	66.83	62.81	59.30
116	74.72	70.68	67.16	63.12	59.60
117	75.08	71.03	67.49	63.43	59.89
118	75.44	71.37	67.82	63.75	60.19
119	75.80	71.71	68.14	64.06	60.49
120	76.16	72.05	68.47	64.37	60.79

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 125 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.35	31.34	29.32	27.31	25.29
2	33.71	31.67	29.65	27.61	25.58
3	34.06	32.01	29.97	27.92	25.87
4	34.41	32.34	30.29	28.23	26.16
5	34.76	32.68	30.62	28.53	26.45
6	35.12	33.02	30.94	28.84	26.74
7	35.47	33.35	31.26	29.15	27.03
8	35.82	33.69	31.59	29.45	27.32
9	36.18	34.03	31.91	29.76	27.61
10	36.53	34.36	32.24	30.07	27.90
11	36.88	34.70	32.56	30.37	28.19
12	37.24	35.03	32.88	30.68	28.48
13	37.59	35.37	33.21	30.99	28.77
14	37.94	35.71	33.53	31.29	29.06
15	38.29	36.04	33.85	31.60	29.35
16	38.65	36.38	34.18	31.91	29.64
17	39.00	36.71	34.50	32.21	29.93
18	39.35	37.05	34.82	32.52	30.22
19	39.71	37.39	35.15	32.83	30.51
20	40.06	37.72	35.47	33.13	30.80
21	40.41	38.06	35.79	33.44	31.09
22	40.76	38.39	36.12	33.75	31.38
23	41.12	38.73	36.44	34.05	31.67
24	41.47	39.07	36.76	34.36	31.96
25	41.82	39.40	37.09	34.67	32.25
26	42.18	39.74	37.41	34.97	32.54
27	42.53	40.08	37.74	35.28	32.83
28	42.88	40.41	38.06	35.59	33.12
29	43.24	40.75	38.38	35.89	33.41
30	43.59	41.08	38.71	36.20	33.70

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Table B-3.—*Pole circumferences for Douglas fir and southern yellow pine*—Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR — 125 FOOT POLE —con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
31	43.94	41.42	39.03	36.51	33.99
32	44.29	41.76	39.35	36.82	34.28
33	44.65	42.09	39.68	37.12	34.57
34	45.00	42.43	40.00	37.43	34.86
35	45.35	42.76	40.32	37.74	35.15
36	45.71	43.10	40.65	38.04	35.44
37	46.06	43.44	40.97	38.35	35.73
38	46.41	43.77	41.29	38.66	36.02
39	46.76	44.11	41.62	38.96	36.31
40	47.12	44.45	41.94	39.27	36.60
41	47.47	44.78	42.26	39.58	36.89
42	47.82	45.12	42.59	39.88	37.18
43	48.18	45.45	42.91	40.19	37.47
44	48.53	45.79	43.24	40.50	37.76
45	48.88	46.13	43.56	40.80	38.05
46	49.24	46.46	43.88	41.11	38.34
47	49.59	46.80	44.21	41.42	38.63
48	49.94	47.13	44.53	41.72	38.92
49	50.29	47.47	44.85	42.03	39.21
50	50.65	47.81	45.18	42.34	39.50
51	51.00	48.14	45.50	42.64	39.79
52	51.35	48.48	45.82	42.95	40.08
53	51.71	48.82	46.15	43.26	40.37
54	52.06	49.15	46.47	43.56	40.66
55	52.41	49.49	46.79	43.87	40.95
56	52.76	49.82	47.12	44.18	41.24
57	53.12	50.16	47.44	44.48	41.53
58	53.47	50.50	47.76	44.79	41.82
59	53.82	50.83	48.09	45.10	42.11
60	54.18	51.17	48.41	45.40	42.39
61	54.53	51.50	48.74	45.71	42.68
62	54.88	51.84	49.06	46.02	42.97
63	55.24	52.18	49.38	46.32	43.26
64	55.59	52.51	49.71	46.63	43.55
65	55.94	52.85	50.03	46.94	43.84
66	56.29	53.18	50.35	47.24	44.13
67	56.65	53.52	50.68	47.55	44.42
68	57.00	53.86	51.00	47.86	44.71
69	57.35	54.19	51.32	48.16	45.00
70	57.71	54.53	51.65	48.47	45.29
71	58.06	54.87	51.97	48.78	45.58
72	58.41	55.20	52.29	49.08	45.87
73	58.76	55.54	52.62	49.39	46.16
74	59.12	55.87	52.94	49.70	46.45
75	59.47	56.21	53.26	50.00	46.74
76	59.82	56.55	53.59	50.31	47.03
77	60.18	56.88	53.91	50.62	47.32
78	60.53	57.22	54.24	50.92	47.61
79	60.88	57.55	54.56	51.23	47.90
80	61.24	57.89	54.88	51.54	48.19

Table B-3.–*Pole circumferences for Douglas fir and southern yellow pine*–Continued

SOUTHERN YELLOW PINE AND DOUGLAS FIR					125 FOOT POLE–con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
81	61.59	58.23	55.21	51.84	48.48
82	61.94	58.56	55.53	52.15	48.77
83	62.29	58.90	55.85	52.46	49.06
84	62.65	59.24	56.18	52.76	49.35
85	63.00	59.57	56.50	53.07	49.64
86	63.35	59.91	56.82	53.38	49.93
87	63.71	60.24	57.15	53.68	50.22
88	64.06	60.58	57.47	53.99	50.51
89	64.41	60.92	57.79	54.30	50.80
90	64.76	61.25	58.12	54.61	51.09
91	65.12	61.59	58.44	54.91	51.38
92	65.47	61.92	58.76	55.22	51.67
93	65.82	62.26	59.09	55.53	51.96
94	66.18	62.60	59.41	55.83	52.25
95	66.53	62.93	59.74	56.14	52.54
96	66.88	63.27	60.06	56.45	52.83
97	67.24	63.61	60.38	56.75	53.12
98	67.59	63.94	60.71	57.06	53.41
99	67.94	64.28	61.03	57.37	53.70
100	68.29	64.61	61.35	57.67	53.99
101	68.65	64.95	61.68	57.98	54.28
102	69.00	65.29	62.00	58.29	54.57
103	69.35	65.62	62.32	58.59	54.86
104	69.71	65.96	62.65	58.90	55.15
105	70.06	66.29	62.97	59.21	55.44
106	70.41	66.63	63.29	59.51	55.73
107	70.76	66.97	63.62	59.82	56.02
108	71.12	67.30	63.94	60.13	56.31
109	71.47	67.64	64.26	60.43	56.60
110	71.82	67.97	64.59	60.74	56.89
111	72.18	68.31	64.91	61.05	57.18
112	72.53	68.65	65.24	61.35	57.47
-------------GROUND LINE (12 FEET, 0 INCHES)--------------					
113	72.88	68.98	65.56	61.66	57.76
114	73.24	69.32	65.88	61.97	58.05
115	73.59	69.66	66.21	62.27	58.34
116	73.94	69.99	66.53	62.58	58.63
117	74.29	70.33	66.85	62.89	58.92
118	74.65	70.66	67.18	63.19	59.21
119	75.00	71.00	67.50	63.50	59.50
120	75.35	71.34	67.82	63.81	59.79
121	75.71	71.67	68.15	64.11	60.08
122	76.06	72.01	68.47	64.42	60.37
123	76.41	72.34	68.79	64.73	60.66
124	76.76	72.68	69.12	65.03	60.95
125	77.12	73.02	69.44	65.34	61.24

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Table B-4.–*Pole circumferences for western red cedar*

WESTERN RED CEDAR

30 FOOT POLE

DISTANCE FROM TOP FEET	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	27.00	25.00	23.00	21.00
1	27.54	25.52	23.50	21.48
2	28.08	26.04	24.00	21.96
3	28.63	26.56	24.50	22.44
4	29.17	27.08	25.00	22.92
5	29.71	27.60	25.50	23.40
6	30.25	28.13	26.00	23.88
7	30.79	28.65	26.50	24.35
8	31.33	29.17	27.00	24.83
9	31.88	29.69	27.50	25.31
10	32.42	30.21	28.00	25.79
11	32.96	30.73	28.50	26.27
12	33.50	31.25	29.00	26.75
13	34.04	31.77	29.50	27.23
14	34.58	32.29	30.00	27.71
15	35.12	32.81	30.50	28.19
16	35.67	33.33	31.00	28.67
17	36.21	33.85	31.50	29.15
18	36.75	34.37	32.00	29.63
19	37.29	34.90	32.50	30.10
20	37.83	35.42	33.00	30.58
21	38.37	35.94	33.50	31.06
22	38.92	36.46	34.00	31.54
23	39.46	36.98	34.50	32.02
24	40.00	37.50	35.00	32.50
------GROUND LINE (5 FEET, 6 INCHES)-------				
25	40.54	38.02	35.50	32.98
26	41.08	38.54	36.00	33.46
27	41.62	39.06	36.50	33.94
28	42.17	39.58	37.00	34.42
29	42.71	40.10	37.50	34.90
30	43.25	40.62	38.00	35.37

WESTERN RED CEDAR

35 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	31.00	29.00	27.00	25.00	23.00	21.00
1	31.59	29.57	27.53	25.52	23.50	21.47
2	32.17	30.14	28.07	26.03	24.00	21.93
3	32.76	30.71	28.60	26.55	24.50	22.40
4	33.34	31.28	29.14	27.07	25.00	22.86
5	33.93	31.84	29.67	27.59	25.50	23.33
6	34.52	32.41	30.21	28.10	26.00	23.79
7	35.10	32.98	30.74	28.62	26.50	24.26
8	35.69	33.55	31.28	29.14	27.00	24.72
9	36.28	34.12	31.81	29.66	27.50	25.19
10	36.86	34.69	32.34	30.17	28.00	25.66

Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR — 35 FOOT POLE—**con.**

DISTANCE FROM TOP FEET	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
11	37.45	35.26	32.88	30.69	28.50	26.12
12	38.03	35.83	33.41	31.21	29.00	26.59
13	38.62	36.40	33.95	31.72	29.50	27.05
14	39.21	36.97	34.48	32.24	30.00	27.52
15	39.79	37.53	35.02	32.76	30.50	27.98
16	40.38	38.10	35.55	33.28	31.00	28.45
17	40.97	38.67	36.09	33.79	31.50	28.91
18	41.55	39.24	36.62	34.31	32.00	29.38
19	42.14	39.81	37.16	34.83	32.50	29.84
20	42.72	40.38	37.69	35.34	33.00	30.31
21	43.31	40.95	38.22	35.86	33.50	30.78
22	43.90	41.52	38.76	36.38	34.00	31.24
23	44.48	42.09	39.29	36.90	34.50	31.71
24	45.07	42.66	39.83	37.41	35.00	32.17
25	45.66	43.22	40.36	37.93	35.50	32.64
26	46.24	43.79	40.90	38.45	36.00	33.10
27	46.83	44.36	41.43	38.97	36.50	33.57
28	47.41	44.93	41.97	39.48	37.00	34.03
29	48.00	45.50	42.50	40.00	37.50	34.50
----------------GROUND LINE (6 FEET, 0 INCHES)--------------------						
30	48.59	46.07	43.03	40.52	38.00	34.97
31	49.17	46.64	43.57	41.03	38.50	35.43
32	49.76	47.21	44.10	41.55	39.00	35.90
33	50.34	47.78	44.64	42.07	39.50	36.36
34	50.93	48.34	45.17	42.59	40.00	36.83
35	51.52	48.91	45.71	43.10	40.50	37.29

WESTERN RED CEDAR — 40 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.60	31.59	29.56	27.53	25.51	23.49	21.46
2	34.21	32.18	30.12	28.06	26.03	23.97	21.91
3	34.81	32.76	30.68	28.59	26.54	24.46	22.37
4	35.41	33.35	31.24	29.12	27.06	24.94	22.82
5	36.01	33.94	31.79	29.65	27.57	25.43	23.28
6	36.62	34.53	32.35	30.18	28.09	25.91	23.74
7	37.22	35.12	32.91	30.71	28.60	26.40	24.19
8	37.82	35.71	33.47	31.24	29.12	26.88	24.65
9	38.43	36.29	34.03	31.76	29.63	27.37	25.10
10	39.03	36.88	34.59	32.29	30.15	27.85	25.56
11	39.63	37.47	35.15	32.82	30.66	28.34	26.01
12	40.24	38.06	35.71	33.35	31.18	28.82	26.47
13	40.84	38.65	36.26	33.88	31.69	29.31	26.93
14	41.44	39.24	36.82	34.41	32.21	29.79	27.38
15	42.04	39.82	37.38	34.94	32.72	30.28	27.84
16	42.65	40.41	37.94	35.47	33.24	30.76	28.29
17	43.25	41.00	38.50	36.00	33.75	31.25	28.75
18	43.85	41.59	39.06	36.53	34.26	31.74	29.21
19	44.46	42.18	39.62	37.06	34.78	32.22	29.66
20	45.06	42.76	40.18	37.59	35.29	32.71	30.12

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR — 40 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
21	45.66	43.35	40.74	38.12	35.81	33.19	30.57
22	46.26	43.94	41.29	38.65	36.32	33.68	31.03
23	46.87	44.53	41.85	39.18	36.84	34.16	31.49
24	47.47	45.12	42.41	39.71	37.35	34.65	31.94
25	48.07	45.71	42.97	40.24	37.87	35.13	32.40
26	48.68	46.29	43.53	40.76	38.38	35.62	32.85
27	49.28	46.88	44.09	41.29	38.90	36.10	33.31
28	49.88	47.47	44.65	41.82	39.41	36.59	33.76
29	50.49	48.06	45.21	42.35	39.93	37.07	34.22
30	51.09	48.65	45.76	42.88	40.44	37.56	34.68
31	51.69	49.24	46.32	43.41	40.96	38.04	35.13
32	52.29	49.82	46.88	43.94	41.47	38.53	35.59
33	52.90	50.41	47.44	44.47	41.99	39.01	36.04
GROUND LINE (6 FEET, 0 INCHES)							
34	53.50	51.00	48.00	45.00	42.50	39.50	36.50
35	54.10	51.59	48.56	45.53	43.01	39.99	36.96
36	54.71	52.18	49.12	46.06	43.53	40.47	37.41
37	55.31	52.76	49.68	46.59	44.04	40.96	37.87
38	55.91	53.35	50.24	47.12	44.56	41.44	38.32
39	56.51	53.94	50.79	47.65	45.07	41.93	38.78
40	57.12	54.53	51.35	48.18	45.59	42.41	39.24

WESTERN RED CEDAR — 45 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.59	31.58	29.55	27.53	25.50	23.47	21.45
2	34.18	32.15	30.10	28.05	26.00	23.95	21.90
3	34.77	32.73	30.65	28.58	26.50	24.42	22.35
4	35.36	33.31	31.21	29.10	27.00	24.90	22.79
5	35.95	33.88	31.76	29.63	27.50	25.37	23.24
6	36.54	34.46	32.31	30.15	28.00	25.85	23.69
7	37.13	35.04	32.86	30.68	28.50	26.32	24.14
8	37.72	35.62	33.41	31.21	29.00	26.79	24.59
9	38.31	36.19	33.96	31.73	29.50	27.27	25.04
10	38.90	36.77	34.51	32.26	30.00	27.74	25.49
11	39.49	37.35	35.06	32.78	30.50	28.22	25.94
12	40.08	37.92	35.62	33.31	31.00	28.69	26.38
13	40.67	38.50	36.17	33.83	31.50	29.17	26.83
14	41.26	39.08	36.72	34.36	32.00	29.64	27.28
15	41.85	39.65	37.27	34.88	32.50	30.12	27.73
16	42.44	40.23	37.82	35.41	33.00	30.59	28.18
17	43.03	40.81	38.37	35.94	33.50	31.06	28.63
18	43.62	41.38	38.92	36.46	34.00	31.54	29.08
19	44.21	41.96	39.47	36.99	34.50	32.01	29.53
20	44.79	42.54	40.03	37.51	35.00	32.49	29.97

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR — 45 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
21	45.38	43.12	40.58	38.04	35.50	32.96	30.42
22	45.97	43.69	41.13	38.56	36.00	33.44	30.87
23	46.56	44.27	41.68	39.09	36.50	33.91	31.32
24	47.15	44.85	42.23	39.62	37.00	34.38	31.77
25	47.74	45.42	42.78	40.14	37.50	34.86	32.22
26	48.33	46.00	43.33	40.67	38.00	35.33	32.67
27	48.92	46.58	43.88	41.19	38.50	35.81	33.12
28	49.51	47.15	44.44	41.72	39.00	36.28	33.56
29	50.10	47.73	44.99	42.24	39.50	36.76	34.01
30	50.69	48.31	45.54	42.77	40.00	37.23	34.46
31	51.28	48.88	46.09	43.29	40.50	37.71	34.91
32	51.87	49.46	46.64	43.82	41.00	38.18	35.36
33	52.46	50.04	47.19	44.35	41.50	38.65	35.81
34	53.05	50.62	47.74	44.87	42.00	39.13	36.26
35	53.64	51.19	48.29	45.40	42.50	39.60	36.71
36	54.23	51.77	48.85	45.92	43.00	40.08	37.15
37	54.82	52.35	49.40	46.45	43.50	40.55	37.60
38	55.41	52.92	49.95	46.97	44.00	41.03	38.05
----------GROUND LINE (6 FEET, 6 INCHES)----------							
39	56.00	53.50	50.50	47.50	44.50	41.50	38.50
40	56.59	54.08	51.05	48.03	45.00	41.97	38.95
41	57.18	54.65	51.60	48.55	45.50	42.45	39.40
42	57.77	55.23	52.15	49.08	46.00	42.92	39.85
43	58.36	55.81	52.71	49.60	46.50	43.40	40.29
44	58.95	56.38	53.26	50.13	47.00	43.87	40.74
45	59.54	56.96	53.81	50.65	47.50	44.35	41.19

WESTERN RED CEDAR — 50 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.58	31.56	29.53	27.51	25.49	23.47	21.43
2	34.16	32.11	30.07	28.02	25.98	23.93	21.86
3	34.74	32.67	30.60	28.53	26.47	24.40	22.30
4	35.32	33.23	31.14	29.05	26.95	24.86	22.73
5	35.90	33.78	31.67	29.56	27.44	25.33	23.16
6	36.48	34.34	32.20	30.07	27.93	25.80	23.59
7	37.06	34.90	32.74	30.58	28.42	26.26	24.02
8	37.64	35.45	33.27	31.09	28.91	26.73	24.45
9	38.22	36.01	33.81	31.60	29.40	27.19	24.89
10	38.80	36.57	34.34	32.11	29.89	27.66	25.32
11	39.37	37.12	34.87	32.63	30.37	28.12	25.75
12	39.95	37.68	35.41	33.14	30.86	28.59	26.18
13	40.53	38.24	35.94	33.65	31.35	29.06	26.61
14	41.11	38.80	36.48	34.16	31.84	29.52	27.05
15	41.69	39.35	37.01	34.67	32.33	29.99	27.48
16	42.27	39.91	37.55	35.18	32.82	30.45	27.91
17	42.85	40.47	38.08	35.69	33.31	30.92	28.34
18	43.43	41.02	38.61	36.20	33.80	31.39	28.77
19	44.01	41.58	39.15	36.72	34.28	31.85	29.20
20	44.59	42.14	39.68	37.23	34.77	32.32	29.64

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR

50 FOOT POLE—**con.**

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
21	45.17	42.69	40.22	37.74	35.26	32.78	30.07
22	45.75	43.25	40.75	38.25	35.75	33.25	30.50
23	46.33	43.81	41.28	38.76	36.24	33.72	30.93
24	46.91	44.36	41.82	39.27	36.73	34.18	31.36
25	47.49	44.92	42.35	39.78	37.22	34.65	31.80
26	48.07	45.48	42.89	40.30	37.70	35.11	32.23
27	48.65	46.03	43.42	40.81	38.19	35.58	32.66
28	49.23	46.59	43.95	41.32	38.68	36.05	33.09
29	49.81	47.15	44.49	41.83	39.17	36.51	33.52
30	50.39	47.70	45.02	42.34	39.66	36.98	33.95
31	50.97	48.26	45.56	42.85	40.15	37.44	34.39
32	51.55	48.82	46.09	43.36	40.64	37.91	34.82
33	52.12	49.37	46.62	43.87	41.12	38.37	35.25
34	52.70	49.93	47.16	44.39	41.61	38.84	35.68
35	53.28	50.49	47.69	44.90	42.10	39.31	36.11
36	53.86	51.05	48.23	45.41	42.59	39.77	36.55
37	54.44	51.60	48.76	45.92	43.08	40.24	36.98
38	55.02	52.16	49.30	46.43	43.57	40.70	37.41
39	55.60	52.72	49.83	46.94	44.06	41.17	37.84
40	56.18	53.27	50.36	47.45	44.55	41.64	38.27
41	56.76	53.83	50.90	47.97	45.03	42.10	38.70
42	57.34	54.39	51.43	48.48	45.52	42.57	39.14
----------------------GROUND LINE (7 FEET, 0 INCHES)----------------------							
43	57.92	54.94	51.97	48.99	46.01	43.03	39.57
44	58.50	55.50	52.50	45.50	46.50	43.50	40.00
45	59.08	56.06	53.03	50.01	46.99	43.97	40.43
46	59.66	56.61	53.57	50.52	47.48	44.43	40.86
47	60.24	57.17	54.10	51.03	47.97	44.90	41.30
48	60.82	57.73	54.64	51.55	48.45	45.36	41.73
49	61.40	58.28	55.17	52.06	48.94	45.83	42.16
50	61.98	58.84	55.70	52.57	49.43	46.30	42.59

WESTERN RED CEDAR

55 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.57	31.54	29.52	27.50	25.48	23.45	21.43
2	34.14	32.08	30.04	28.00	25.96	23.90	21.86
3	34.71	32.62	30.56	28.50	26.44	24.35	22.29
4	35.29	33.16	31.08	29.00	26.92	24.80	22.71
5	35.86	33.70	31.60	29.50	27.40	25.24	23.14
6	36.43	34.24	32.12	30.00	27.88	25.69	23.57
7	37.00	34.79	32.64	30.50	28.36	26.14	24.00
8	37.57	35.33	33.16	31.00	28.84	26.59	24.43
9	38.14	35.87	33.68	31.50	29.32	27.04	24.86
10	38.71	36.41	34.20	32.00	29.80	27.49	25.29

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR						55 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
11	39.29	36.95	34.72	32.50	30.28	27.94	25.71
12	39.86	37.49	35.24	33.00	30.76	28.39	26.14
13	40.43	38.03	35.77	33.50	31.23	28.84	26.57
14	41.00	38.57	36.29	34.00	31.71	29.29	27.00
15	41.57	39.11	36.81	34.50	32.19	29.73	27.43
16	42.14	39.65	37.33	35.00	32.67	30.18	27.86
17	42.71	40.19	37.85	35.50	33.15	30.63	28.29
18	43.29	40.73	38.37	36.00	33.63	31.08	28.71
19	43.86	41.28	38.89	36.50	34.11	31.53	29.14
20	44.43	41.82	39.41	37.00	34.59	31.98	29.57
21	45.00	42.36	39.93	37.50	35.07	32.43	30.00
22	45.57	42.90	40.45	38.00	35.55	32.88	30.43
23	46.14	43.44	40.97	38.50	36.03	33.33	30.86
24	46.71	43.98	41.49	39.00	36.51	33.78	31.29
25	47.29	44.52	42.01	39.50	36.99	34.22	31.71
26	47.86	45.06	42.53	40.00	37.47	34.67	32.14
27	48.43	45.60	43.05	40.50	37.95	35.12	32.57
28	49.00	46.14	43.57	41.00	38.43	35.57	33.00
29	49.57	46.68	44.09	41.50	38.91	36.02	33.43
30	50.14	47.22	44.61	42.00	39.39	36.47	33.86
31	50.71	47.77	45.13	42.50	39.87	36.92	34.29
32	51.29	48.31	45.65	43.00	40.35	37.37	34.71
33	51.86	48.85	46.17	43.50	40.83	37.82	35.14
34	52.43	49.39	46.69	44.00	41.31	38.27	35.57
35	53.00	49.93	47.21	44.50	41.79	38.71	36.00
36	53.57	50.47	47.73	45.00	42.27	39.16	36.43
37	54.14	51.01	48.26	45.50	42.74	39.61	36.86
38	54.71	51.55	48.78	46.00	43.22	40.06	37.29
39	55.29	52.09	49.30	46.50	43.70	40.51	37.71
40	55.86	52.63	49.82	47.00	44.18	40.96	38.14
41	56.43	53.17	50.34	47.50	44.66	41.41	38.57
42	57.00	53.71	50.86	48.00	45.14	41.86	39.00
43	57.57	54.26	51.38	48.50	45.62	42.31	39.43
44	58.14	54.80	51.90	49.00	46.10	42.76	39.86
45	58.71	55.34	52.42	49.50	46.58	43.20	40.29
46	59.29	55.88	52.94	50.00	47.06	43.65	40.71
47	59.86	56.42	53.46	50.50	47.54	44.10	41.14
----------GROUND LINE (7 FEET, 6 INCHES)----------							
48	60.43	56.96	53.98	51.00	48.02	44.55	41.57
49	61.00	57.50	54.50	51.50	48.50	45.00	42.00
50	61.57	58.04	55.02	52.00	48.98	45.45	42.43
51	62.14	58.58	55.54	52.50	49.46	45.90	42.86
52	62.71	59.12	56.06	53.00	49.94	46.35	43.29
53	63.29	59.66	56.58	53.50	50.42	46.80	43.71
54	63.86	60.20	57.10	54.00	50.90	47.24	44.14
55	64.43	60.74	57.62	54.50	51.38	47.69	44.57

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR						60 FOOT POLE	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.56	31.53	29.51	27.49	25.47	23.44	21.42
2	34.11	32.06	30.02	27.98	25.94	23.87	21.83
3	34.67	32.58	30.53	28.47	26.42	24.31	22.25
4	35.22	33.11	31.04	28.96	26.89	24.74	22.67
5	35.78	33.64	31.55	29.45	27.36	25.18	23.08
6	36.33	34.17	32.06	29.94	27.83	25.61	23.50
7	36.89	34.69	32.56	30.44	28.31	26.05	23.92
8	37.44	35.22	33.07	30.93	28.78	26.48	24.33
9	38.00	35.75	33.58	31.42	29.25	26.92	24.75
10	38.56	36.28	34.09	31.91	29.72	27.35	25.17
11	39.11	36.81	34.60	32.40	30.19	27.79	25.58
12	39.67	37.33	35.11	32.89	30.67	28.22	26.00
13	40.22	37.86	35.62	33.38	31.14	28.66	26.42
14	40.78	38.39	36.13	33.87	31.61	29.09	26.83
15	41.33	38.92	36.64	34.36	32.08	29.53	27.25
16	41.89	39.44	37.15	34.85	32.56	29.96	27.67
17	42.44	39.97	37.66	35.34	33.03	30.40	28.08
18	43.00	40.50	38.17	35.83	33.50	30.83	28.50
19	43.56	41.03	38.68	36.32	33.97	31.27	28.92
20	44.11	41.56	39.19	36.81	34.44	31.70	29.33
21	44.67	42.08	39.69	37.31	34.92	32.14	29.75
22	45.22	42.61	40.20	37.80	35.39	32.57	30.17
23	45.78	43.14	40.71	38.29	35.86	33.01	30.58
24	46.33	43.67	41.22	38.78	36.33	33.44	31.00
25	46.89	44.19	41.73	39.27	36.81	33.88	31.42
26	47.44	44.72	42.24	39.76	37.28	34.31	31.83
27	48.00	45.25	42.75	40.25	37.75	34.75	32.25
28	48.56	45.78	43.26	40.74	38.22	35.19	32.67
29	49.11	46.31	43.77	41.23	38.69	35.62	33.08
30	49.67	46.83	44.28	41.72	39.17	36.06	33.50
31	50.22	47.36	44.79	42.21	39.64	36.49	33.92
32	50.78	47.89	45.30	42.70	40.11	36.93	34.33
33	51.33	48.42	45.81	43.19	40.58	37.36	34.75
34	51.89	48.94	46.31	43.69	41.06	37.80	35.17
35	52.44	49.47	46.82	44.18	41.53	38.23	35.58
36	53.00	50.00	47.33	44.67	42.00	38.67	36.00
37	53.56	50.53	47.84	45.16	42.47	39.10	36.42
38	54.11	51.06	48.35	45.65	42.94	39.54	36.83
39	54.67	51.58	48.86	46.14	43.42	39.97	37.25
40	55.22	52.11	49.37	46.63	43.89	40.41	37.67
41	55.78	52.64	49.88	47.12	44.36	40.84	38.08
42	56.33	53.17	50.39	47.61	44.83	41.28	38.50
43	56.89	53.69	50.90	48.10	45.31	41.71	39.92
44	57.44	54.22	51.41	48.59	45.78	42.15	39.33
45	58.00	54.75	51.92	49.08	46.25	42.58	39.75
46	58.56	55.28	52.43	49.57	46.72	43.02	40.17
47	59.11	55.81	52.94	50.06	47.19	43.45	40.58
48	59.67	56.33	53.44	50.56	47.67	43.89	41.00
49	60.22	56.86	53.95	51.05	48.14	44.32	41.42
50	60.78	57.39	54.46	51.54	48.61	44.76	41.83

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR — 60 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
51	61.33	57.92	54.97	52.03	49.08	45.19	42.25
GROUND LINE (8 FEET, 0 INCHES)							
52	61.89	58.44	55.48	52.52	49.56	45.63	42.67
53	62.44	58.97	55.99	53.01	50.03	46.06	43.08
54	63.00	59.50	56.50	53.50	50.50	46.50	43.50
55	63.56	60.03	57.01	53.99	50.97	46.94	43.92
56	64.11	60.56	57.52	54.48	51.44	47.37	44.33
57	64.67	61.08	58.03	54.97	51.92	47.81	44.75
58	65.22	61.61	58.54	55.46	52.39	48.24	45.17
59	65.78	62.14	59.05	55.95	52.86	48.68	45.58
60	66.33	62.67	59.56	56.44	53.33	49.11	46.00

WESTERN RED CEDAR — 65 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.54	31.52	29.50	27.47	25.45	23.42	21.41
2	34.08	32.03	30.00	27.95	25.90	23.85	21.81
3	34.63	32.55	30.50	28.42	26.35	24.27	22.22
4	35.17	33.07	31.00	28.90	26.80	24.69	22.63
5	35.71	33.58	31.50	29.37	27.25	25.12	23.03
6	36.25	34.10	32.00	29.85	27.69	25.54	23.44
7	36.80	34.62	32.50	30.32	28.14	25.97	23.85
8	37.34	35.14	33.00	30.80	28.59	26.39	24.25
9	37.88	35.65	33.50	31.27	29.04	26.81	24.66
10	38.42	36.17	34.00	31.75	29.49	27.24	25.07
11	38.97	36.69	34.50	32.22	29.94	27.66	25.47
12	39.51	37.20	35.00	32.69	30.39	28.08	25.88
13	40.05	37.72	35.50	33.17	30.84	28.51	26.29
14	40.59	38.24	36.00	33.64	31.29	28.93	26.69
15	41.14	38.75	36.50	34.12	31.74	29.36	27.10
16	41.68	39.27	37.00	34.59	32.19	29.78	27.51
17	42.22	39.79	37.50	35.07	32.64	30.20	27.92
18	42.76	40.31	38.00	35.54	33.08	30.63	28.32
19	43.31	40.82	38.50	36.02	33.53	31.05	28.73
20	43.85	41.34	39.00	36.49	33.98	31.47	29.14
21	44.39	41.86	39.50	36.97	34.43	31.90	29.54
22	44.93	42.37	40.00	37.44	34.88	32.32	29.95
23	45.47	42.89	40.50	37.92	35.33	32.75	30.36
24	46.02	43.41	41.00	38.39	35.78	33.17	30.76
25	46.56	43.92	41.50	38.86	36.23	33.59	31.17
26	47.10	44.44	42.00	39.34	36.68	34.02	31.58
27	47.64	44.96	42.50	39.81	37.13	34.44	31.98
28	48.19	45.47	43.00	40.29	37.58	34.86	32.39
29	48.73	45.99	43.50	40.76	38.03	35.29	32.80
30	49.27	46.51	44.00	41.24	38.47	35.71	33.20

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR						65 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
31	49.81	47.03	44.50	41.71	38.92	36.14	33.61
32	50.36	47.54	45.00	42.19	39.37	36.56	34.02
33	50.90	48.06	45.50	42.66	39.82	36.98	34.42
34	51.44	48.58	46.00	43.14	40.27	37.41	34.83
35	51.98	49.09	46.50	43.61	40.72	37.83	35.24
36	52.53	49.61	47.00	44.08	41.17	38.25	35.64
37	53.07	50.13	47.50	44.56	41.62	38.68	36.05
38	53.61	50.64	48.00	45.03	42.07	39.10	36.46
39	54.15	51.16	48.50	45.51	42.52	39.53	36.86
40	54.69	51.68	49.00	45.98	42.97	39.95	37.27
41	55.24	52.19	49.50	46.46	43.42	40.37	37.68
42	55.78	52.71	50.00	46.93	43.86	40.80	38.08
43	56.32	53.23	50.50	47.41	44.31	41.22	38.49
44	56.86	53.75	51.00	47.88	44.76	41.64	38.90
45	57.41	54.26	51.50	48.36	45.21	42.07	39.31
46	57.95	54.78	52.00	48.83	45.66	42.49	39.71
47	58.49	55.30	52.50	49.31	46.11	42.92	40.12
48	59.03	55.81	53.00	49.78	46.56	43.34	40.53
49	59.58	56.33	53.50	50.25	47.01	43.76	40.93
50	60.12	56.85	54.00	50.73	47.46	44.19	41.34
51	60.66	57.36	54.50	51.20	47.91	44.61	41.75
52	61.20	57.88	55.00	51.68	48.36	45.03	42.15
53	61.75	58.40	55.50	52.15	48.81	45.46	42.56
54	62.29	58.92	56.00	52.63	49.25	45.88	42.97
55	62.83	59.43	56.50	53.10	49.70	46.31	43.37
56	63.37	59.95	57.00	53.58	50.15	46.73	43.78
GROUND LINE (8 FEET, 6 INCHES)							
57	63.92	60.47	57.50	54.05	50.60	47.15	44.19
58	64.46	60.98	58.00	54.53	51.05	47.58	44.59
59	65.00	61.50	58.50	55.00	51.50	48.00	45.00
60	65.54	62.02	59.00	55.47	51.95	48.42	45.41
61	66.08	62.53	59.50	55.95	52.40	48.85	45.81
62	66.63	63.05	60.00	56.42	52.85	49.27	46.22
63	67.17	63.57	60.50	56.90	53.30	49.69	46.63
64	67.71	64.08	61.00	57.37	53.75	50.12	47.03
65	68.25	64.60	61.50	57.85	54.19	50.54	47.44

WESTERN RED CEDAR						70 FOOT POLE	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00	21.00
1	33.53	31.51	29.48	27.46	25.44	23.41	21.39
2	34.06	32.02	29.97	27.92	25.88	23.83	21.78
3	34.59	32.52	30.45	28.38	26.31	24.24	22.17
4	35.13	33.03	30.94	28.84	26.75	24.66	22.56
5	35.66	33.54	31.42	29.30	27.19	25.07	22.95
6	36.19	34.05	31.91	29.77	27.63	25.48	23.34
7	36.72	34.55	32.39	30.23	28.06	25.90	23.73
8	37.25	35.06	32.88	30.69	28.50	26.31	24.13
9	37.78	35.57	33.36	31.15	28.94	26.73	24.52
10	38.31	36.08	33.84	31.61	29.38	27.14	24.91

Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR						70 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
11	38.84	36.59	34.33	32.07	29.81	27.55	25.30
12	39.38	37.09	34.81	32.53	30.25	27.97	25.69
13	39.91	37.60	35.30	32.99	30.69	28.38	26.08
14	40.44	38.11	35.78	33.45	31.13	28.80	26.47
15	40.97	38.62	36.27	33.91	31.56	29.21	26.86
16	41.50	39.13	36.75	34.38	32.00	29.63	27.25
17	42.03	39.63	37.23	34.84	32.44	30.04	27.64
18	42.56	40.14	37.72	35.30	32.88	30.45	28.03
19	43.09	40.65	38.20	35.76	33.31	30.87	28.42
20	43.63	41.16	38.69	36.22	33.75	31.28	28.81
21	44.16	41.66	39.17	36.68	34.19	31.70	29.20
22	44.69	42.17	39.66	37.14	34.63	32.11	29.59
23	45.22	42.68	40.14	37.60	35.06	32.52	29.98
24	45.75	43.19	40.63	38.06	35.50	32.94	30.38
25	46.28	43.70	41.11	38.52	35.94	33.35	30.77
26	46.81	44.20	41.59	38.98	36.38	33.77	31.16
27	47.34	44.71	42.08	39.45	36.81	34.18	31.55
28	47.88	45.22	42.56	39.91	37.25	34.59	31.94
29	48.41	45.73	43.05	40.37	37.69	35.01	32.33
30	48.94	46.23	43.53	40.83	38.13	35.42	32.72
31	49.47	46.74	44.02	41.29	38.56	35.84	33.11
32	50.00	47.25	44.50	41.75	39.00	36.25	33.50
33	50.53	47.76	44.98	42.21	39.44	36.66	33.89
34	51.06	48.27	45.47	42.67	39.88	37.08	34.28
35	51.59	48.77	45.95	43.13	40.31	37.49	34.67
36	52.13	49.28	46.44	43.59	40.75	37.91	35.06
37	52.66	49.79	46.92	44.05	41.19	38.32	35.45
38	53.19	50.30	47.41	44.52	41.63	38.73	35.84
39	53.72	50.80	47.89	44.98	42.06	39.15	36.23
40	54.25	51.31	48.38	45.44	42.50	39.56	36.63
41	54.78	51.82	48.86	45.90	42.94	39.98	37.02
42	55.31	52.33	49.34	46.36	43.38	40.39	37.41
43	55.84	52.84	49.83	46.82	43.81	40.80	37.80
44	56.38	53.34	50.31	47.28	44.25	41.22	38.19
45	56.91	53.85	50.80	47.74	44.69	41.63	38.58
46	57.44	54.36	51.28	48.20	45.13	42.05	38.97
47	57.97	54.87	51.77	48.66	45.56	42.46	39.36
48	58.50	55.38	52.25	49.13	46.00	42.88	39.75
49	59.03	55.88	52.73	49.59	46.44	43.29	40.14
50	59.56	56.39	53.22	50.05	46.88	43.70	40.53
51	60.09	56.90	53.70	50.51	47.31	44.12	40.92
52	60.63	57.41	54.19	50.97	47.75	44.53	41.31
53	61.16	57.91	54.67	51.43	48.19	44.95	41.70
54	61.69	58.42	55.16	51.89	48.63	45.36	42.09
55	62.22	58.93	55.64	52.35	49.06	45.77	42.48
56	62.75	59.44	56.13	52.81	49.50	46.19	42.88
57	63.28	59.95	56.61	53.27	49.94	46.60	43.27
58	63.81	60.45	57.09	53.73	50.38	47.02	43.66
59	64.34	60.96	57.58	54.20	50.81	47.43	44.05
60	64.88	61.47	58.06	54.66	51.25	47.84	44.44

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR						70 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES	CLASS 4 CIRC. INCHES
----------------------GROUND LINE (9 FEET, 0 INCHES)--------------------------							
61	65.41	61.98	58.55	55.12	51.69	48.26	44.83
62	65.94	62.48	59.03	55.58	52.13	48.67	45.22
63	66.47	62.99	59.52	56.04	52.56	49.09	45.61
64	67.00	63.50	60.00	56.50	53.00	49.50	46.00
65	67.53	64.01	60.48	56.96	53.44	49.91	46.39
66	68.06	64.52	60.97	57.42	53.88	50.33	46.78
67	68.59	65.02	61.45	57.88	54.31	50.74	47.17
68	69.13	65.53	61.94	58.34	54.75	51.16	47.56
69	69.66	66.04	62.42	58.80	55.19	51.57	47.95
70	70.19	66.55	62.91	59.27	55.63	51.98	48.34

WESTERN RED CEDAR						75 FOOT POLE
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.51	31.49	29.47	27.45	25.43	23.41
2	34.03	31.99	29.94	27.90	25.86	23.81
3	34.54	32.48	30.41	28.35	26.28	24.22
4	35.06	32.97	30.88	28.80	26.71	24.62
5	35.57	33.46	31.36	29.25	27.14	25.03
6	36.09	33.96	31.83	29.70	27.57	25.43
7	36.60	34.45	32.30	30.14	27.99	25.84
8	37.12	34.94	32.77	30.59	28.42	26.25
9	37.63	35.43	33.24	31.04	28.85	26.65
10	38.14	35.93	33.71	31.49	29.28	27.06
11	38.66	36.42	34.18	31.94	29.70	27.46
12	39.17	36.91	34.65	32.39	30.13	27.87
13	39.69	37.41	35.12	32.84	30.56	28.28
14	40.20	37.90	35.59	33.29	30.99	28.68
15	40.72	38.39	36.07	33.74	31.41	29.09
16	41.23	38.88	36.54	34.19	31.84	29.49
17	41.75	39.38	37.01	34.64	32.27	29.90
18	42.26	39.87	37.48	35.09	32.70	30.30
19	42.78	40.36	37.95	35.54	33.12	30.71
20	43.29	40.86	38.42	35.99	33.55	31.12
21	43.80	41.35	38.89	36.43	33.98	31.52
22	44.32	41.84	39.36	36.88	34.41	31.93
23	44.83	42.33	39.83	37.33	34.83	32.33
24	45.35	42.83	40.30	37.78	35.26	32.74
25	45.86	43.32	40.78	38.23	35.69	33.14
26	46.38	43.81	41.25	38.68	36.12	33.55
27	46.89	44.30	41.72	39.13	36.54	33.96
28	47.41	44.80	42.19	39.58	36.97	34.36
29	47.92	45.29	42.66	40.03	37.40	34.77
30	48.43	45.78	43.13	40.48	37.83	35.17

Table B-4.–*Pole circumferences for western red cedar*–Continued

75 FOOT POLE—con.

WESTERN RED CEDAR

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
31	48.95	46.28	43.60	40.93	38.25	35.58
32	49.46	46.77	44.07	41.38	38.68	35.99
33	49.98	47.26	44.54	41.83	39.11	36.39
34	50.49	47.75	45.01	42.28	39.54	36.80
35	51.01	48.25	45.49	42.72	39.96	37.20
36	51.52	48.74	45.96	43.17	40.39	37.61
37	52.04	49.23	46.43	43.62	40.82	38.01
38	52.55	49.72	46.90	44.07	41.25	38.42
39	53.07	50.22	47.37	44.52	41.67	38.83
40	53.58	50.71	47.84	44.97	42.10	39.23
41	54.09	51.20	48.31	45.42	42.53	39.64
42	54.61	51.70	48.78	45.87	42.96	40.04
43	55.12	52.19	49.25	46.32	43.38	40.45
44	55.64	52.68	49.72	46.77	43.81	40.86
45	56.15	53.17	50.20	47.22	44.24	41.26
46	56.67	53.67	50.67	47.67	44.67	41.67
47	57.18	54.16	51.14	48.12	45.09	42.07
48	57.70	54.65	51.61	48.57	45.52	42.48
49	58.21	55.14	52.08	49.01	45.95	42.88
50	58.72	55.64	52.55	49.46	46.38	43.29
51	59.24	56.13	53.02	49.91	46.80	43.70
52	59.75	56.62	53.49	50.36	47.23	44.10
53	60.27	57.12	53.96	50.81	47.66	44.51
54	60.78	57.61	54.43	51.26	48.09	44.91
55	61.30	58.10	54.91	51.71	48.51	45.32
56	61.81	58.59	55.38	52.16	48.94	45.72
57	62.33	59.09	55.85	52.61	49.37	46.13
58	62.84	59.58	56.32	53.06	49.80	46.54
59	63.36	60.07	56.79	53.51	50.22	46.94
60	63.87	60.57	57.26	53.96	50.65	47.35
61	64.38	61.06	57.73	54.41	51.08	47.75
62	64.90	61.55	58.20	54.86	51.51	48.16
63	65.41	62.04	58.67	55.30	51.93	48.57
64	65.93	62.54	59.14	55.75	52.36	48.97
65	66.44	63.03	59.62	56.20	52.79	49.38
------------------GROUND LINE (9 FEET, 6 INCHES)------------------						
66	66.96	63.52	60.09	56.65	53.22	49.78
67	67.47	64.01	60.56	57.10	53.64	50.19
68	67.99	64.51	61.03	57.55	54.07	50.59
69	68.50	65.00	61.50	58.00	54.50	51.00
70	69.01	65.49	61.97	58.45	54.93	51.41
71	69.53	65.99	62.44	58.90	55.36	51.81
72	70.04	66.48	62.91	59.35	55.78	52.22
73	70.56	66.97	63.38	59.80	56.21	52.62
74	71.07	67.46	63.86	60.25	56.64	53.03
75	71.59	67.96	64.33	60.70	57.07	53.43

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	80 FOOT POLE CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.51	31.49	29.46	27.44	25.42	23.39
2	34.01	31.97	29.92	27.88	25.84	23.78
3	34.52	32.46	30.38	28.32	26.26	24.18
4	35.03	32.95	30.84	28.76	26.68	24.57
5	35.53	33.43	31.30	29.20	27.09	24.96
6	36.04	33.92	31.76	29.64	27.51	25.35
7	36.55	34.41	32.22	30.07	27.93	25.74
8	37.05	34.89	32.68	30.51	28.35	26.14
9	37.56	35.38	33.14	30.95	28.77	26.53
10	38.07	35.86	33.59	31.39	29.19	26.92
11	38.57	36.35	34.05	31.83	29.61	27.31
12	39.08	36.84	34.51	32.27	30.03	27.70
13	39.59	37.32	34.97	32.71	30.45	28.09
14	40.09	37.81	35.43	33.15	30.86	28.49
15	40.60	38.30	35.89	33.59	31.28	28.88
16	41.11	38.78	36.35	34.03	31.70	29.27
17	41.61	39.27	36.81	34.47	32.12	29.66
18	42.12	39.76	37.27	34.91	32.54	30.05
19	42.63	40.24	37.73	35.34	32.96	30.45
20	43.14	40.73	38.19	35.78	33.38	30.84
21	43.64	41.22	38.65	36.22	33.80	31.23
22	44.15	41.70	39.11	36.66	34.22	31.62
23	44.66	42.19	39.57	37.10	34.64	32.01
24	45.16	42.68	40.03	37.54	35.05	32.41
25	45.67	43.16	40.49	37.98	35.47	32.80
26	46.18	43.65	40.95	38.42	35.89	33.19
27	46.68	44.14	41.41	38.86	36.31	33.58
28	47.19	44.62	41.86	39.30	36.73	33.97
29	47.70	45.11	42.32	39.74	37.15	34.36
30	48.20	45.59	42.78	40.18	37.57	34.76
31	48.71	46.08	43.24	40.61	37.99	35.15
32	49.22	46.57	43.70	41.05	38.41	35.54
33	49.72	47.05	44.16	41.49	38.82	35.93
34	50.23	47.54	44.62	41.93	39.24	36.32
35	50.74	48.03	45.08	42.37	39.66	36.72
36	51.24	48.51	45.54	42.81	40.08	37.11
37	51.75	49.00	46.00	43.25	40.50	37.50
38	52.26	49.49	46.46	43.69	40.92	37.89
39	52.76	49.97	46.92	44.13	41.34	38.28
40	53.27	50.46	47.38	44.57	41.76	38.68
41	53.78	50.95	47.84	45.01	42.18	39.07
42	54.28	51.43	48.30	45.45	42.59	39.46
43	54.79	51.92	48.76	45.89	43.01	39.85
44	55.30	52.41	49.22	46.32	43.43	40.24
45	55.80	52.89	49.68	46.76	43.85	40.64
46	56.31	53.38	50.14	47.20	44.27	41.03
47	56.82	53.86	50.59	47.64	44.69	41.42
48	57.32	54.35	51.05	48.08	45.11	41.81
49	57.83	54.84	51.51	48.52	45.53	42.20
50	58.34	55.32	51.97	48.96	45.95	42.59

Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR

80 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
51	58.84	55.81	52.43	49.40	46.36	42.99
52	59.35	56.30	52.89	49.84	46.78	43.38
53	59.86	56.78	53.35	50.28	47.20	43.77
54	60.36	57.27	53.81	50.72	47.62	44.16
55	60.87	57.76	54.27	51.16	48.04	44.55
56	61.38	58.24	54.73	51.59	48.46	44.95
57	61.89	58.73	55.19	52.03	48.88	45.34
58	62.39	59.22	55.65	52.47	49.30	45.73
59	62.90	59.70	56.11	52.91	49.72	46.12
60	63.41	60.19	56.57	53.35	50.14	46.51
61	63.91	60.68	57.03	53.79	50.55	46.91
62	64.42	61.16	57.49	54.23	50.97	47.30
63	64.93	61.65	57.95	54.67	51.39	47.69
64	65.43	62.14	58.41	55.11	51.81	48.08
65	65.94	62.62	58.86	55.55	52.23	48.47
66	66.45	63.11	59.32	55.99	52.65	48.86
67	66.95	63.59	59.78	56.43	53.07	49.26
68	67.46	64.08	60.24	56.86	53.49	49.65
69	67.97	64.57	60.70	57.30	53.91	50.04
------------------GROUND LINE (10 FEET, 0 INCHES)------------------						
70	68.47	65.05	61.16	57.74	54.32	50.43
71	68.98	65.54	61.62	58.18	54.74	50.82
72	69.49	66.03	62.08	58.62	55.16	51.22
73	69.99	66.51	62.54	59.06	55.58	51.61
74	70.50	67.00	63.00	59.50	56.00	52.00
75	71.01	67.49	63.46	59.94	56.42	52.39
76	71.51	67.97	63.92	60.38	56.84	52.78
77	72.02	68.46	64.38	60.82	57.26	53.18
78	72.53	68.95	64.84	61.26	57.68	53.57
79	73.03	69.43	65.30	61.70	58.09	53.96
80	73.54	69.92	65.76	62.14	58.51	54.35

WESTERN RED CEDAR

85 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.49	31.47	29.45	27.43	25.41	23.39
2	33.99	31.95	29.90	27.86	25.81	23.77
3	34.48	32.42	30.35	28.29	26.22	24.16
4	34.97	32.90	30.80	28.72	26.62	24.54
5	35.47	33.37	31.25	29.15	27.03	24.93
6	35.96	33.85	31.70	29.58	27.43	25.32
7	36.46	34.32	32.15	30.01	27.84	25.70
8	36.95	34.80	32.59	30.44	28.24	26.09
9	37.44	35.27	33.04	30.87	28.65	26.47
10	37.94	35.75	33.49	31.30	29.05	26.86

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR

85 FOOT POLE–con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
11	38.43	36.22	33.94	31.73	29.46	27.25
12	38.92	36.70	34.39	32.16	29.86	27.63
13	39.42	37.17	34.84	32.59	30.27	28.02
14	39.91	37.65	35.29	33.03	30.67	28.41
15	40.41	38.12	35.74	33.46	31.08	28.79
16	40.90	38.59	36.19	33.89	31.48	29.18
17	41 39	39.07	36.64	34.32	31.89	29.56
18	41.89	39.54	37.09	34.75	32.29	29.95
19	42.38	40.02	37.54	35.18	32.70	30.34
20	42.87	40.49	37.99	35.61	33.10	30.72
21	43.37	40.97	38.44	36.04	33.51	31.11
22	43.86	41.44	38.89	36.47	33.91	31.49
23	44.35	41.92	39.34	36.90	34.32	31.88
24	44.85	42.39	39.78	37.33	34.72	32.27
25	45.34	42.87	40.23	37.76	35.13	32.65
26	45.84	43.34	40.68	38.19	35.53	33.04
27	46.33	43.82	41.13	38.62	35.94	33.42
28	46.82	44.29	41.58	39.05	36.34	33.81
29	47.32	44.77	42.03	39.48	36.75	34.20
30	47.81	45.24	42.48	39.91	37.15	34.58
31	48.30	45.72	42.93	40.34	37.56	34.97
32	48.80	46.19	43.38	40.77	37.96	35.35
33	49.29	46.66	43.83	41.20	38.37	35.74
34	49.78	47.14	44.28	41.63	38.77	36.13
35	50.28	47.61	44.73	42.06	39.18	36.51
36	50.77	48.09	45.18	42.49	39.58	36.90
37	51.27	48.56	45.63	42.92	39.99	37.28
38	51.76	49.04	46.08	43.35	40.39	37.67
39	52.25	49.51	46.53	43.78	40.80	38.06
40	52.75	49.99	46.97	44.22	41.20	38.44
41	53.24	50.46	47.42	44.65	41.61	38.83
42	53.73	50.94	47.87	45.08	42.01	39.22
43	54.23	51.41	48.32	45.51	42.42	39.60
44	54.72	51.89	48.77	45.94	42.82	39.99
45	55.22	52.36	49.22	46.37	43.23	40.37
46	55.71	52.84	49.67	46.80	43.63	40.76
47	56.20	53.31	50.12	47.23	44.04	41.15
48	56.70	53.78	50.57	47.66	44.44	41.53
49	57.19	54.26	51.02	48.09	44.85	41.92
50	57.68	54.73	51.47	48.52	45.25	42.30
51	58.18	55.21	51.92	48.95	45.66	42.69
52	58.67	55.68	52.37	49.38	46.06	43.08
53	59.16	56.16	52.82	49.81	46.47	43.46
54	59.66	56.63	53.27	50.24	46.87	43.85
55	60.15	57.11	53.72	50.67	47.28	44.23
56	60.65	57.58	54.16	51.10	47.68	44.62
57	61.14	58.06	54.61	51.53	48.09	45.01
58	61.63	58.53	55.06	51.96	48.49	45.39
59	62.13	59.01	55.51	52.39	48.90	45.78
60	62.62	59.48	55.96	52.82	49.30	46.16

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Table B-4.—*Pole circumferences for western red cedar*—Continued

85 FOOT POLE—con.

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
61	63.11	59.96	56.41	53.25	49.71	46.55
62	63.61	60.43	56.86	53.68	50.11	46.94
63	64.10	60.91	57.31	54.11	50.52	47.32
64	64.59	61.38	57.76	54.54	50.92	47.71
65	65.09	61.85	58.21	54.97	51.33	48.09
66	65.58	62.33	58.66	55.41	51.73	48.48
67	66.08	62.80	59.11	55.84	52.14	48.87
68	66.57	63.28	59.56	56.27	52.54	49.25
69	67.06	63.75	60.01	56.70	52.95	49.64
70	67.56	64.23	60.46	57.13	53.35	50.03
71	68.05	64.70	60.91	57.56	53.76	50.41
72	68.54	65.18	61.35	57.99	54.16	50.80
73	69.04	65.65	61.80	58.42	54.57	51.18
74	69.53	66.13	62.25	58.85	54.97	51.57
----------------GROUND LINE (10 FEET, 6 INCHES)----------------						
75	70.03	66.60	62.70	59.28	55.38	51.96
76	70.52	67.08	63.15	59.71	55.78	52.34
77	71.01	67.55	63.60	60.14	56.19	52.73
78	71.51	68.03	64.05	60.57	56.59	53.11
79	72.00	68.50	64.50	61.00	57.00	53.50
80	72.49	68.97	64.95	61.43	57.41	53.89
81	72.99	69.45	65.40	61.86	57.81	54.27
82	73.48	69.92	65.85	62.29	58.22	54.66
83	73.97	70.40	66.30	62.72	58.62	55.04
84	74.47	70.87	66.75	63.15	59.03	55.43
85	74.96	71.35	67.20	63.58	59.43	55.82

90 FOOT POLE

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00	23.00
1	33.48	31.46	29.44	27.42	25.40	23.38
2	33.96	31.93	29.88	27.85	25.80	23.75
3	34.45	32.39	30.32	28.27	26.20	24.13
4	34.93	32.86	30.76	28.69	26.60	24.50
5	35.41	33.32	31.20	29.11	26.99	24.88
6	35.89	33.79	31.64	29.54	27.39	25.25
7	36.37	34.25	32.08	29.96	27.79	25.63
8	36.86	34.71	32.52	30.38	28.19	26.00
9	37.34	35.18	32.96	30.80	28.59	26.38
10	37.82	35.64	33.40	31.23	28.99	26.75
11	38.30	36.11	33.85	31.65	29.39	27.13
12	38.79	36.57	34.29	32.07	29.79	27.50
13	39.27	37.04	34.73	32.49	30.18	27.88
14	39.75	37.50	35.17	32.92	30.58	28.25
15	40.23	37.96	35.61	33.34	30.98	28.63
16	40.71	38.43	36.05	33.76	31.38	29.00
17	41.20	38.89	36.49	34.18	31.78	29.38
18	41.68	39.36	36.93	34.61	32.18	29.75
19	42.16	39.82	37.37	35.03	32.58	30.13
20	42.64	40.29	37.81	35.45	32.98	30.50

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR					90 FOOT POLE—con.	
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
21	43.12	40.75	38.25	35.88	33.38	30.88
22	43.61	41.21	38.69	36.30	33.77	31.25
23	44.09	41.68	39.13	36.72	34.17	31.63
24	44.57	42.14	39.57	37.14	34.57	32.00
25	45.05	42.61	40.01	37.57	34.97	32.38
26	45.54	43.07	40.45	37.99	35.37	32.75
27	46.02	43.54	40.89	38.41	35.77	33.13
28	46.50	44.00	41.33	38.83	36.17	33.50
29	46.98	44.46	41.77	39.26	36.57	33.88
30	47.46	44.93	42.21	39.68	36.96	34.25
31	47.95	45.39	42.65	40.10	37.36	34.63
32	48.43	45.86	43.10	40.52	37.76	35.00
33	48.91	46.32	43.54	40.95	38.16	35.38
34	49.39	46.79	43.98	41.37	38.56	35.75
35	49.87	47.25	44.42	41.79	38.96	36.13
36	50.36	47.71	44.86	42.21	39.36	36.50
37	50.84	48.18	45.30	42.64	39.76	36.88
38	51.32	48.64	45.74	43.06	40.15	37.25
39	51.80	49.11	46.18	43.48	40.55	37.63
40	52.29	49.57	46.62	43.90	40.95	38.00
41	52.77	50.04	47.06	44.33	41.35	38.38
42	53.25	50.50	47.50	44.75	41.75	38.75
43	53.73	50.96	47.94	45.17	42.15	39.13
44	54.21	51.43	48.38	45.60	42.55	39.50
45	54.70	51.89	48.82	46.02	42.95	39.88
46	55.18	52.36	49.26	46.44	43.35	40.25
47	55.66	52.82	49.70	46.86	43.74	40.63
48	56.14	53.29	50.14	47.29	44.14	41.00
49	56.62	53.75	50.58	47.71	44.54	41.38
50	57.11	54.21	51.02	48.13	44.94	41.75
51	57.59	54.68	51.46	48.55	45.34	42.13
52	58.07	55.14	51.90	48.98	45.74	42.50
53	58.55	55.61	52.35	49.40	46.14	42.88
54	59.04	56.07	52.79	49.82	46.54	43.25
55	59.52	56.54	53.23	50.24	46.93	43.63
56	60.00	57.00	53.67	50.67	47.33	44.00
57	60.48	57.46	54.11	51.09	47.73	44.38
58	60.96	57.93	54.55	51.51	48.13	44.75
59	61.45	58.39	54.99	51.93	48.53	45.13
60	61.93	58.86	55.43	52.36	48.93	45.50
61	62.41	59.32	55.87	52.78	49.33	45.88
62	62.89	59.79	56.31	53.20	49.73	46.25
63	63.37	60.25	56.75	53.62	50.12	46.63
64	63.86	60.71	57.19	54.05	50.52	47.00
65	64.34	61.18	57.63	54.47	50.92	47.38
66	64.82	61.64	58.07	54.89	51.32	47.75
67	65.30	62.11	58.51	55.32	51.72	48.13
68	65.79	62.57	58.95	55.74	52.12	48.50
69	66.27	63.04	59.39	56.16	52.52	48.88
70	66.75	63.50	59.83	56.58	52.92	49.25

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR — 90 FOOT POLE–con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES	CLASS 3 CIRC. INCHES
71	67.23	63.96	60.27	57.01	53.32	49.63
72	67.71	64.43	60.71	57.43	53.71	50.00
73	68.20	64.89	61.15	57.85	54.11	50.38
74	68.68	65.36	61.60	58.27	54.51	50.75
75	69.16	65.82	62.04	58.70	54.91	51.13
76	69.64	66.29	62.48	59.12	55.31	51.50
77	70.12	66.75	62.92	59.54	55.71	51.88
78	70.61	67.21	63.36	59.96	56.11	52.25
--------GROUND LINE (11 FEET, 0 INCHES)--------						
79	71.09	67.68	63.80	60.39	56.51	52.63
80	71.57	68.14	64.24	60.81	56.90	53.00
81	72.05	68.61	64.68	61.23	57.30	53.38
82	72.54	69.07	65.12	61.65	57.70	53.75
83	73.02	69.54	65.56	62.08	58.10	54.13
84	73.50	70.00	66.00	62.50	58.50	54.50
85	73.98	70.46	66.44	62.92	58.90	54.88
86	74.46	70.93	66.88	63.35	59.30	55.25
87	74.95	71.39	67.32	63.77	59.70	55.63
88	75.43	71.86	67.76	64.19	60.10	56.00
89	75.91	72.32	68.20	64.61	60.49	56.38
90	76.39	72.79	68.64	65.04	60.89	56.75

WESTERN RED CEDAR — 95 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.47	31.46	29.43	27.41	25.39
2	33.94	31.91	29.87	27.82	25.78
3	34.42	32.37	30.30	28.23	26.16
4	34.89	32.82	30.73	28.64	26.55
5	35.36	33.28	31.16	29.05	26.94
6	35.83	33.73	31.60	29.46	27.33
7	36.30	34.19	32.03	29.87	27.71
8	36.78	34.64	32.46	30.28	28.10
9	37.25	35.10	32.89	30.69	26.49
10	37.72	35.55	33.33	31.10	28.88
11	38.19	36.01	33.76	31.51	29.26
12	38.66	36.46	34.19	31.92	29.65
13	39.13	36.92	34.62	32.33	30.04
14	39.61	37.37	35.06	32.74	30.43
15	40.08	37.83	35.49	33.15	30.81
16	40.55	38.28	35.92	33.56	31.20
17	41.02	38.74	36.35	33.97	31.59
18	41.49	39.19	36.79	34.38	31.98
19	41.97	39.65	37.22	34.79	32.37
20	42.44	40.10	37.65	35.20	32.75

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	95 FOOT POLE–con. CLASS 2 CIRC. INCHES
21	42.91	40.56	38.08	35.61	33.14
22	43.38	41.01	38.52	36.02	33.53
23	43.85	41.47	38.95	36.43	33.92
24	44.33	41.92	39.38	36.84	34.30
25	44.80	42.38	39.81	37.25	34.69
26	45.27	42.83	40.25	37.66	35.08
27	45.74	43.29	40.68	38.07	35.47
28	46.21	43.74	41.11	38.48	35.85
29	46.69	44.20	41.54	38.89	36.24
30	47.16	44.65	41.98	39.30	36.63
31	47.63	45.11	42.41	39.71	37.02
32	48.10	45.56	42.84	40.12	37.40
33	48.57	46.02	43.28	40.53	37.79
34	49.04	46.47	43.71	40.94	38.18
35	49.52	46.93	44.14	41.35	38.57
36	49.99	47.38	44.57	41.76	38.96
37	50.46	47.84	45.01	42.17	39.34
38	50.93	48.29	45.44	42.58	39.73
39	51.40	48.75	45.87	42.99	40.12
40	51.88	49.20	46.30	43.40	40.51
41	52.35	49.66	46.74	43.81	40.89
42	52.82	50.11	47.17	44.22	41.28
43	53.29	50.57	47.60	44.63	41.67
44	53.76	51.02	48.03	45.04	42.06
45	54.24	51.48	48.47	45.46	42.44
46	54.71	51.93	48.90	45.87	42.83
47	55.18	52.39	49.33	46.28	43.22
48	55.65	52.84	49.76	46.69	43.61
49	56.12	53.30	50.20	47.10	43.99
50	56.60	53.75	50.63	47.51	44.38
51	57.07	54.21	51.06	47.92	44.77
52	57.54	54.66	51.49	48.33	45.16
53	58.01	55.12	51.93	48.74	45.54
54	58.48	55.57	52.36	49.15	45.93
55	58.96	56.03	52.79	49.56	46.32
56	59.43	56.48	53.22	49.97	46.71
57	59.90	56.94	53.66	50.38	47.10
58	60.37	57.39	54.09	50.79	47.48
59	60.84	57.85	54.52	51.20	47.87
60	61.31	58.30	54.96	51.61	48.26
61	61.79	58.76	55.39	52.02	48.65
62	62.26	59.21	55.82	52.43	49.03
63	62.73	59.67	56.25	52.84	49.42
64	63.20	60.12	56.69	53.25	49.81
65	63.67	60.58	57.12	53.66	50.20
66	64.15	61.03	57.55	54.07	50.58
67	64.62	61.49	57.98	54.48	50.97
68	65.09	61.94	58.42	54.89	51.36
69	65.56	62.40	58.85	55.30	51.75
70	66.03	62.85	59.28	55.71	52.13

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR — 95 FOOT POLE—con.

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
71	66.51	63.31	59.71	56.12	52.52
72	66.98	63.76	60.15	56.53	52.91
73	67.45	64.22	60.58	56.94	53.30
74	67.92	64.67	61.01	57.35	53.69
75	68.39	65.13	61.44	57.76	54.07
76	68.87	65.58	61.88	58.17	54.46
77	69.34	66.04	62.31	58.58	54.85
78	69.81	66.49	62.74	58.99	55.24
79	70.28	66.95	63.17	59.40	55.62
80	70.75	67.40	63.61	59.81	56.01
81	71.22	67.86	64.04	60.22	56.40
82	71.70	68.31	64.47	60.63	56.79
83	72.17	68.77	64.90	61.04	57.17
-------------GROUND LINE (11 FEET, 0 INCHES)---------------					
84	72.64	69.22	65.34	61.45	57.56
85	73.11	69.68	65.77	61.86	57.95
86	73.58	70.13	66.20	62.27	58.34
87	74.06	70.59	66.63	62.68	58.72
88	74.53	71.04	67.07	63.09	59.11
89	75.00	71.50	67.50	63.50	59.50
90	75.47	71.96	67.93	63.91	59.89
91	75.94	72.41	68.37	64.32	60.28
92	76.42	72.87	68.80	64.73	60.66
93	76.89	73.32	69.23	65.14	61.05
94	77.36	73.78	69.66	65.55	61.44
95	77.83	74.23	70.10	65.96	61.83

WESTERN RED CEDAR — 100 FOOT POLE

DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.46	31.44	29.43	27.40	25.38
2	33.93	31.88	29.85	27.81	25.77
3	34.39	32.32	30.28	28.21	26.15
4	34.85	32.77	30.70	28.62	26.53
5	35.31	33.21	31.13	29.02	26.91
6	35.78	33.65	31.55	29.43	27.30
7	36.24	34.09	31.98	29.83	27.68
8	36.70	34.53	32.40	30.23	28.06
9	37.16	34.97	32.83	30.64	28.45
10	37.63	35.41	33.26	31.04	28.83
11	38.09	35.86	33.68	31.45	29.21
12	38.55	36.30	34.11	31.85	29.60
13	39.02	36.74	34.53	32.26	29.98
14	39.48	37.18	34.96	32.66	30.36
15	39.94	37.62	35.38	33.06	30.74
16	40.40	38.06	35.81	33.47	31.13
17	40.87	38.51	36.23	33.87	31.51
18	41.33	38.95	36.66	34.28	31.89
19	41.79	39.39	37.09	34.68	32.28
20	42.26	39.83	37.51	35.09	32.66

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR					100 FOOT POLE—con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
21	42.72	40.27	37.94	35.49	33.04
22	43.18	40.71	38.36	35.89	33.43
23	43.64	41.15	38.79	36.30	33.81
24	44.11	41.60	39.21	36.70	34.19
25	44.57	42.04	39.64	37.11	34.57
26	45.03	42.48	40.06	37.51	34.96
27	45.49	42.92	40.49	37.91	35.34
28	45.96	43.36	40.91	38.32	35.72
29	46.42	43.80	41.34	38.72	36.11
30	46.88	44.24	41.77	39.13	36.49
31	47.35	44.69	42.19	39.53	36.87
32	47.81	45.13	42.62	39.94	37.26
33	48.27	45.57	43.04	40.34	37.64
34	48.73	46.01	43.47	40.74	38.02
35	49.20	46.45	43.89	41.15	38.40
36	49.66	46.89	44.32	41.55	38.79
37	50.12	47.34	44.74	41.96	39.17
38	50.59	47.78	45.17	42.36	39.55
39	51.05	48.22	45.60	42.77	39.94
40	51.51	48.66	46.02	43.17	40.32
41	51.97	49.10	46.45	43.57	40.70
42	52.44	49.54	46.87	43.98	41.09
43	52.90	49.98	47.30	44.38	41.47
44	53.36	50.43	47.72	44.79	41.85
45	53.82	50.87	48.15	45.19	42.23
46	54.29	51.31	48.57	45.60	42.62
47	54.75	51.75	49.00	46.00	43.00
48	55.21	52.19	49.43	46.40	43.38
49	55.68	52.63	49.85	46.81	43.77
50	56.14	53.07	50.28	47.21	44.15
51	56.60	53.52	50.70	47.62	44.53
52	57.06	53.96	51.13	48.02	44.91
53	57.53	54.40	51.55	48.43	45.30
54	57.99	54.84	51.98	48.83	45.68
55	58.45	55.28	52.40	49.23	46.06
56	58.91	55.72	52.83	49.64	46.45
57	59.38	56.16	53.26	50.04	46.83
58	59.84	56.61	53.68	50.45	47.21
59	60.30	57.05	54.11	50.85	47.60
60	60.77	57.49	54.53	51.26	47.98
61	61.23	57.93	54.96	51.66	48.36
62	61.69	58.37	55.38	52.06	48.74
63	62.15	58.81	55.81	52.47	49.13
64	62.62	59.26	56.23	52.87	49.51
65	63.08	59.70	56.66	53.28	49.89
66	63.54	60.14	57.09	53.68	50.28
67	64.01	60.58	57.51	54.09	50.66
68	64.47	61.02	57.94	54.49	51.04
69	64.93	61.46	58.36	54.89	51.43
70	65.39	61.90	58.79	55.30	51.81

Table B-4.–*Pole circumferences for western red cedar*–Continued

100 FOOT POLE—con.

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
71	65.86	62.35	59.21	55.70	52.19
72	66.32	62.79	59.64	56.11	52.57
73	66.78	63.23	60.06	56.51	52.96
74	67.24	63.67	60.49	56.91	53.34
75	67.71	64.11	60.91	57.32	53.72
76	68.17	64.55	61.34	57.72	54.11
77	68.63	64.99	61.77	58.13	54.49
78	69.10	65.44	62.19	58.53	54.87
79	69.56	65.88	62.62	58.94	55.26
80	70.02	66.32	63.04	59.34	55.64
81	70.48	66.76	63.47	59.74	56.02
82	70.95	67.20	63.89	60.15	56.40
83	71.41	67.64	64.32	60.55	56.79
84	71.87	68.09	64.74	60.96	57.17
85	72.34	68.53	65.17	61.36	57.55
86	72.80	68.97	65.60	61.77	57.94
87	73.26	69.41	66.02	62.17	58.32
88	73.72	69.85	66.45	62.57	58.70
-------------GROUND LINE (11 FEET, 0 INCHES)---------------					
89	74.19	70.29	66.87	62.98	59.09
90	74.65	70.73	67.30	63.38	59.47
91	75.11	71.18	67.72	63.79	59.85
92	75.57	71.62	68.15	64.19	60.23
93	76.04	72.06	68.57	64.60	60.62
94	76.50	72.50	69.00	65.00	61.00
95	76.96	72.94	69.43	65.40	61.38
96	77.43	73.38	69.85	65.81	61.77
97	77.89	73.82	70.28	66.21	62.15
98	78.35	74.27	70.70	66.62	62.53
99	78.81	74.71	71.13	67.02	62.91
100	79.28	75.15	71.55	67.43	63.30

105 FOOT POLE

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.45	31.43	29.41	27.39	25.37
2	33.91	31.87	29.83	27.79	25.75
3	34.36	32.30	30.24	28.18	26.12
4	34.82	32.74	30.66	28.58	26.49
5	35.27	33.17	31.07	28.97	26.87
6	35.73	33.61	31.48	29.36	27.24
7	36.18	34.04	31.90	29.76	27.62
8	36.64	34.47	32.31	30.15	27.99
9	37.09	34.91	32.73	30.55	28.36
10	37.55	35.34	33.14	30.94	28.74

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	105 FOOT POLE—con. CLASS 2 CIRC. INCHES
11	38.00	35.78	33.56	31.33	29.11
12	38.45	36.21	33.97	31.73	29.48
13	38.91	36.65	34.38	32.12	29.86
14	39.36	37.08	34.80	32.52	30.23
15	39.82	37.52	35.21	32.91	30.61
16	40.27	37.95	35.63	33.30	30.98
17	40.73	38.38	36.04	33.70	31.35
18	41.18	38.82	36.45	34.09	31.73
19	41.64	39.25	36.87	34.48	32.10
20	42.09	39.69	37.28	34.88	32.47
21	42.55	40.12	37.70	35.27	32.85
22	43.00	40.56	38.11	35.67	33.22
23	43.45	40.99	38.53	36.06	33.60
24	43.91	41.42	38.94	36.45	33.97
25	44.36	41.86	39.35	36.85	34.34
26	44.82	42.29	39.77	37.24	34.72
27	45.27	42.73	40.18	37.64	35.09
28	45.73	43.16	40.60	38.03	35.46
29	46.18	43.60	41.01	38.42	35.84
30	46.64	44.03	41.42	38.82	36.21
31	47.09	44.46	41.84	39.21	36.59
32	47.55	44.90	42.25	39.61	36.96
33	48.00	45.33	42.67	40.00	37.33
34	48.45	45.77	43.08	40.39	37.71
35	48.91	46.20	43.49	40.79	38.08
36	49.36	46.64	43.91	41.18	38.45
37	49.82	47.07	44.32	41.58	38.83
38	50.27	47.51	44.74	41.97	39.20
39	50.73	47.94	45.15	42.36	39.58
40	51.18	48.37	45.57	42.76	39.95
41	51.64	48.81	45.98	43.15	40.32
42	52.09	49.24	46.39	43.55	40.70
43	52.55	49.68	46.81	43.94	41.07
44	53.00	50.11	47.22	44.33	41.44
45	53.45	50.55	47.64	44.73	41.82
46	53.91	50.98	48.05	45.12	42.19
47	54.36	51.41	48.46	45.52	42.57
48	54.82	51.85	48.88	45.91	42.94
49	55.27	52.28	49.29	46.30	43.31
50	55.73	52.72	49.71	46.70	43.69
51	56.18	53.15	50.12	47.09	44.06
52	56.64	53.59	50.54	47.48	44.43
53	57.09	54.02	50.95	47.88	44.81
54	57.55	54.45	51.36	48.27	45.18
55	58.00	54.89	51.78	48.67	45.56
56	58.45	55.32	52.19	49.06	45.93
57	58.91	55.76	52.61	49.45	46.30
58	59.36	56.19	53.02	49.85	46.68
59	59.82	56.63	53.43	50.24	47.05
60	60.27	57.06	53.85	50.64	47.42

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	105 FOOT POLE—con. CLASS 2 CIRC. INCHES
61	60.73	57.49	54.26	51.03	47.80
62	61.18	57.93	54.68	51.42	48.17
63	61.64	58.36	55.09	51.82	48.55
64	62.09	58.80	55.51	52.21	48.92
65	62.55	59.23	55.92	52.61	49.29
66	63.00	59.67	56.33	53.00	49.67
67	63.45	60.10	56.75	53.39	50.04
68	63.91	60.54	57.16	53.79	50.41
69	64.36	60.97	57.58	54.18	50.79
70	64.82	61.40	57.99	54.58	51.16
71	65.27	61.84	58.40	54.97	51.54
72	65.73	62.27	58.82	55.36	51.91
73	66.18	62.71	59.23	55.76	52.28
74	66.64	63.14	59.65	56.15	52.66
75	67.09	63.58	60.06	56.55	53.03
76	67.55	64.01	60.47	56.94	53.40
77	68.00	64.44	60.89	57.33	53.78
78	68.45	64.88	61.30	57.73	54.15
79	68.91	65.31	61.72	58.12	54.53
80	69.36	65.75	62.13	58.52	54.90
81	69.82	66.18	62.55	58.91	55.27
82	70.27	66.62	62.96	59.30	55.65
83	70.73	67.05	63.37	59.70	56.02
84	71.18	67.48	63.79	60.09	56.39
85	71.64	67.92	64.20	60.48	56.77
86	72.09	68.35	64.62	60.88	57.14
87	72.55	68.79	65.03	61.27	57.52
88	73.00	69.22	65.44	61.67	57.89
89	73.45	69.66	65.86	62.06	58.26
90	73.91	70.09	66.27	62.45	58.64
91	74.36	70.53	66.69	62.85	59.01
92	74.82	70.96	67.10	63.24	59.38
-------------GROUND LINE (12 FEET, 0 INCHES)--------------					
93	75.27	71.39	67.52	63.64	59.76
94	75.73	71.83	67.93	64.03	60.13
95	76.18	72.26	68.34	64.42	60.51
96	76.64	72.70	68.76	64.82	60.88
97	77.09	73.13	69.17	65.21	61.25
98	77.55	73.57	69.59	65.61	61.63
99	78.00	74.00	70.00	66.00	62.00
100	78.45	74.43	70.41	66.39	62.37
101	78.91	74.87	70.83	66.79	62.75
102	79.36	75.30	71.24	67.18	63.12
103	79.82	75.74	71.66	67.58	63.49
104	80.27	76.17	72.07	67.97	63.87
105	80.73	76.61	72.48	68.36	64.24

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR					110 FOOT POLE
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.45	31.43	29.41	27.39	25.37
2	33.89	31.86	29.82	27.78	25.73
3	34.34	32.28	30.23	28.17	26.10
4	34.79	32.71	30.63	28.56	26.46
5	35.24	33.14	31.04	28.95	26.83
6	35.68	33.57	31.45	29.34	27.19
7	36.13	34.00	31.86	29.73	27.56
8	36.58	34.42	32.27	30.12	27.92
9	37.02	34.85	32.68	30.50	28.29
10	37.47	35.28	33.09	30.89	28.65
11	37.92	35.71	33.50	31.28	29.02
12	38.37	36.13	33.90	31.67	29.38
13	38.81	36.56	34.31	32.06	29.75
14	39.26	36.99	34.72	32.45	30.12
15	39.71	37.42	35.13	32.84	30.48
16	40.15	37.85	35.54	33.23	30.85
17	40.60	38.27	35.95	33.62	31.21
18	41.05	38.70	36.36	34.01	31.58
19	41.50	39.13	36.76	34.40	31.94
20	41.94	39.56	37.17	34.79	32.31
21	42.39	39.99	37.58	35.18	32.67
22	42.84	40.41	37.99	35.57	33.04
23	43.28	40.84	38.40	35.96	33.40
24	43.73	41.27	38.81	36.35	33.77
25	44.18	41.70	39.22	36.74	34.13
26	44.62	42.12	39.63	37.12	34.50
27	45.07	42.55	40.03	37.51	34.87
28	45.52	42.98	40.44	37.90	35.23
29	45.97	43.41	40.85	38.29	35.60
30	46.41	43.84	41.26	38.68	35.96
31	46.86	44.26	41.67	39.07	36.33
32	47.31	44.69	42.08	39.46	36.69
33	47.75	45.12	42.49	39.85	37.06
34	48.20	45.55	42.89	40.24	37.42
35	48.65	45.98	43.30	40.63	37.79
36	49.10	46.40	43.71	41.02	38.15
37	49.54	46.83	44.12	41.41	38.52
38	49.99	47.26	44.53	41.80	38.88
39	50.44	47.69	44.94	42.19	39.25
40	50.88	48.12	45.35	42.58	39.62
41	51.33	48.54	45.75	42.97	39.98
42	51.78	48.97	46.16	43.36	40.35
43	52.23	49.40	46.57	43.75	40.71
44	52.67	49.83	46.98	44.13	41.08
45	53.12	50.25	47.39	44.52	41.44
46	53.57	50.68	47.80	44.91	41.81
47	54.01	51.11	48.21	45.30	42.17
48	54.46	51.54	48.62	45.69	42.54
49	54.91	51.97	49.02	46.08	42.90
50	55.36	52.39	49.43	46.47	43.27

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR					110 FOOT POLE–con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
51	55.80	52.82	49.84	46.86	43.63
52	56.25	53.25	50.25	47.25	44.00
53	56.70	53.68	50.66	47.64	44.37
54	57.14	54.11	51.07	48.03	44.73
55	57.59	54.53	51.48	48.42	45.10
56	58.04	54.96	51.88	48.81	45.46
57	58.49	55.39	52.29	49.20	45.83
58	58.93	55.82	52.70	49.59	46.19
59	59.38	56.25	53.11	49.98	46.56
60	59.83	56.67	53.52	50.37	46.92
61	60.27	57.10	53.93	50.75	47.29
62	60.72	57.53	54.34	51.14	47.65
63	61.17	57.96	54.75	51.53	48.02
64	61.62	58.38	55.15	51.92	48.38
65	62.06	58.81	55.56	52.31	48.75
66	62.51	59.24	55.97	52.70	49.12
67	62.96	59.67	56.38	53.09	49.48
68	63.40	60.10	56.79	53.48	49.85
69	63.85	60.52	57.20	53.87	50.21
70	64.30	60.95	57.61	54.26	50.58
71	64.75	61.38	58.01	54.65	50.94
72	65.19	61.81	58.42	55.04	51.31
73	65.64	62.24	58.83	55.43	51.67
74	66.09	62.66	59.24	55.82	52.04
75	66.53	63.09	59.65	56.21	52.40
76	66.98	63.52	60.06	56.60	52.77
77	67.43	63.95	60.47	56.99	53.13
78	67.87	64.37	60.87	57.37	53.50
79	68.32	64.80	61.28	57.76	53.87
80	68.77	65.23	61.69	58.15	54.23
81	69.22	65.66	62.10	58.54	54.60
82	69.66	66.09	62.51	58.93	54.96
83	70.11	66.51	62.92	59.32	55.33
84	70.56	66.94	63.33	59.71	55.69
85	71.00	67.37	63.74	60.10	56.06
86	71.45	67.80	64.14	60.49	56.42
87	71.90	68.23	64.55	60.88	56.79
88	72.35	68.65	64.96	61.27	57.15
89	72.79	69.08	65.37	61.66	57.52
90	73.24	69.51	65.78	62.05	57.88
91	73.69	69.94	66.19	62.44	58.25
92	74.13	70.37	66.60	62.83	58.62
93	74.58	70.79	67.00	63.22	58.98
94	75.03	71.22	67.41	63.61	59.35
95	75.48	71.65	67.82	64.00	59.71
96	75.92	72.08	68.23	64.38	60.08
97	76.37	72.50	68.64	64.77	60.44
-------------GROUND LINE (12 FEET, 0 INCHES)---------------					
98	76.82	72.93	69.05	65.16	60.81
99	77.26	73.36	69.46	65.55	61.17
100	77.71	73.79	69.87	65.94	61.54

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR					110 FOOT POLE —con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
101	78.16	74.22	70.27	66.33	61.90
102	78.61	74.64	70.68	66.72	62.27
103	79.05	75.07	71.09	67.11	62.63
104	79.50	75.50	71.50	67.50	63.00
105	79.95	75.93	71.91	67.89	63.37
106	80.39	76.36	72.32	68.28	63.73
107	80.84	76.78	72.73	68.67	64.10
108	81.29	77.21	73.13	69.06	64.46
109	81.74	77.64	73.54	69.45	64.83
110	82.18	78.07	73.95	69.84	65.19

WESTERN RED CEDAR					115 FOOT POLE
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.44	31.42	29.40	27.38	25.36
2	33.87	31.83	29.80	27.76	25.72
3	34.31	32.25	30.20	28.14	26.07
4	34.74	32.67	30.60	28.52	26.43
5	35.18	33.09	31.00	28.90	26.79
6	35.61	33.50	31.39	29.28	27.15
7	36.05	33.92	31.79	29.67	27.50
8	36.49	34.34	32.19	30.05	27.86
9	36.92	34.76	32.59	30.43	28.22
10	37.36	35.17	32.99	30.81	28.58
11	37.79	35.59	33.39	31.19	28.94
12	38.23	36.01	33.79	31.57	29.29
13	38.67	36.43	34.19	31.95	29.65
14	39.10	36.84	34.59	32.33	30.01
15	39.54	37.26	34.99	32.71	30.37
16	39.97	37.68	35.39	33.09	30.72
17	40.41	38.10	35.78	33.47	31.08
18	40.84	38.51	36.18	33.85	31.44
19	41.28	38.93	36.58	34.23	31.80
20	41.72	39.35	36.98	34.61	32.16
21	42.15	39.77	37.38	35.00	32.51
22	42.59	40.18	37.78	35.38	32.87
23	43.02	40.60	38.18	35.76	33.23
24	43.46	41.02	38.58	36.14	33.59
25	43.89	41.44	38.98	36.52	33.94
26	44.33	41.85	39.38	36.90	34.30
27	44.77	42.27	39.78	37.28	34.66
28	45.20	42.69	40.17	37.66	35.02
29	45.64	43.11	40.57	38.04	35.38
30	46.07	43.52	40.97	38.42	35.73

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET					115 FOOT POLE –con.
	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
31	46.51	43.94	41.37	38.80	36.09
32	46.94	44.36	41.77	39.18	36.45
33	47.38	44.78	42.17	39.56	36.81
34	47.82	45.19	42.57	39.94	37.17
35	48.25	45.61	42.97	40.33	37.52
36	48.69	46.03	43.37	40.71	37.88
37	49.12	46.44	43.77	41.09	38.24
38	49.56	46.86	44.17	41.47	38.60
39	50.00	47.28	44.56	41.85	38.95
40	50.43	47.70	44.96	42.23	39.31
41	50.87	48.11	45.36	42.61	39.67
42	51.30	48.53	45.76	42.99	40.03
43	51.74	48.95	46.16	43.37	40.39
44	52.17	49.37	46.56	43.75	40.74
45	52.61	49.78	46.96	44.13	41.10
46	53.05	50.20	47.36	44.51	41.46
47	53.48	50.62	47.76	44.89	41.82
48	53.92	51.04	48.16	45.28	42.17
49	54.35	51.45	48.56	45.66	42.53
50	54.79	51.87	48.95	46.04	42.89
51	55.22	52.29	49.35	46.42	43.25
52	55.66	52.71	49.75	46.80	43.61
53	56.10	53.12	50.15	47.18	43.96
54	56.53	53.54	50.55	47.56	44.32
55	56.97	53.96	50.95	47.94	44.68
56	57.40	54.38	51.35	48.32	45.04
57	57.84	54.79	51.75	48.70	45.39
58	58.28	55.21	52.15	49.08	45.75
59	58.71	55.63	52.55	49.46	46.11
60	59.15	56.05	52.94	49.84	46.47
61	59.58	56.46	53.34	50.22	46.83
62	60.02	56.88	53.74	50.61	47.18
63	60.45	57.30	54.14	50.99	47.54
64	60.89	57.72	54.54	51.37	47.90
65	61.33	58.13	54.94	51.75	48.26
66	61.76	58.55	55.34	52.13	48.61
67	62.20	58.97	55.74	52.51	48.97
68	62.63	59.39	56.14	52.89	49.33
69	63.07	59.80	56.54	53.27	49.69
70	63.50	60.22	56.94	53.65	50.05
71	63.94	60.64	57.33	54.03	50.40
72	64.38	61.06	57.73	54.41	50.76
73	64.81	61.47	58.13	54.79	51.12
74	65.25	61.89	58.53	55.17	51.48
75	65.68	62.31	58.93	55.56	51.83
76	66.12	62.72	59.33	55.94	52.19
77	66.56	63.14	59.73	56.32	52.55
78	66.99	63.56	60.13	56.70	52.91
79	67.43	63.98	50.53	57.08	53.27
80	67.86	64.39	60.93	57.46	53.62

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Table B-4.—*Pole circumferences for western red cedar*—Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	115 FOOT POLE—con. CLASS 2 CIRC. INCHES
81	68.30	64.81	61.33	57.84	53.98
82	68.73	65.23	61.72	58.22	54.34
83	69.17	65.65	62.12	58.60	54.70
84	69.61	66.06	62.52	58.98	55.06
85	70.04	66.48	62.92	59.36	55.41
86	70.48	66.90	63.32	59.74	55.77
87	70.91	67.32	63.72	60.12	56.13
88	71.35	67.73	64.12	60.50	56.49
89	71.78	68.15	64.52	60.89	56.84
90	72.22	68.57	64.92	61.27	57.20
91	72.66	68.99	65.32	61.65	57.56
92	73.09	69.40	65.72	62.03	57.92
93	73.53	69.82	66.11	62.41	58.28
94	73.96	70.24	66.51	62.79	58.63
95	74.40	70.66	66.91	63.17	58.99
96	74.83	71.07	67.31	63.55	59.35
97	75.27	71.49	67.71	63.93	59.71
98	75.71	71.91	68.11	64.31	60.06
99	76.14	72.33	68.51	64.69	60.42
100	76.58	72.74	68.91	65.07	60.78
101	77.01	73.16	69.31	65.45	61.14
102	77.45	73.58	69.71	65.83	61.50
-------------GROUND LINE (12 FEET, 0 INCHES)---------------					
103	77.89	74.00	70.11	66.22	61.85
104	78.32	74.41	70.50	66.60	62.21
105	78.76	74.83	70.90	66.98	62.57
106	79.19	75.25	71.30	67.36	62.93
107	79.63	75.67	71.70	67.74	63.28
108	80.06	76.08	72.10	68.12	63.64
109	80.50	76.50	72.50	68.50	64.00
110	80.94	76.92	72.90	68.88	64.36
111	81.37	77.33	73.30	69.26	64.72
112	81.81	77.75	73.70	69.64	65.07
113	82.24	78.17	74.10	70.02	65.43
114	82.68	78.59	74.50	70.40	65.79
115	83.11	79.00	74.89	70.78	66.15

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	120 FOOT POLE CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.43	31.41	29.39	27.37	25.35
2	33.86	31.82	29.79	27.75	25.70
3	34.29	32.24	30.18	28.12	26.05
4	34.72	32.65	30.58	28.49	26.40
5	35.15	33.06	30.97	28.86	26.75
6	35.58	33.47	31.37	29.24	27.11
7	36.01	33.89	31.76	29.61	27.46
8	36.44	34.30	32.16	29.98	27.81
9	36.87	34.71	32.55	30.36	28.16
10	37.30	35.12	32.95	30.73	28.51

Table B-4.–*Pole circumferences for western red cedar*–Continued

					120 FOOT POLE—con.
WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
11	37.73	35.54	33.34	31.10	28.86
12	38.16	35.95	33.74	31.47	29.21
13	38.59	36.36	34.13	31.85	29.56
14	39.02	36.77	34.53	32.22	29.91
15	39.45	37.18	34.92	32.59	30.26
16	39.88	37.60	35.32	32.96	30.61
17	40.31	38.01	35.71	33.34	30.96
18	40.74	38.42	36.11	33.71	31.32
19	41.17	38.83	36.50	34.08	31.67
20	41.60	39.25	36.89	34.46	32.02
21	42.03	39.66	37.29	34.83	32.37
22	42.46	40.07	37.68	35.20	32.72
23	42.89	40.48	38.08	35.57	33.07
24	43.32	40.89	38.47	35.95	33.42
25	43.75	41.31	38.87	36.32	33.77
26	44.18	41.72	39.26	36.69	34.12
27	44.61	42.13	39.66	37.07	34.47
28	45.04	42.54	40.05	37.44	34.82
29	45.46	42.96	40.45	37.81	35.18
30	45.89	43.37	40.84	38.18	35.53
31	46.32	43.78	41.24	38.56	35.88
32	46.75	44.19	41.63	38.93	36.23
33	47.18	44.61	42.03	39.30	36.58
34	47.61	45.02	42.42	39.68	36.93
35	48.04	45.43	42.82	40.05	37.28
36	48.47	45.84	43.21	40.42	37.63
37	48.90	46.25	43.61	40.79	37.98
38	49.33	46.67	44.00	41.17	38.33
39	49.76	47.08	44.39	41.54	38.68
40	50.19	47.49	44.79	41.91	39.04
41	50.62	47.90	45.18	42.29	39.39
42	51.05	48.32	45.58	42.66	39.74
43	51.48	48.73	45.97	43.03	40.09
44	51.91	49.14	46.37	43.40	40.44
45	52.34	49.55	46.76	43.78	40.79
46	52.77	49.96	47.16	44.15	41.14
47	53.20	50.38	47.55	44.52	41.49
48	53.63	50.79	47.95	44.89	41.84
49	54.06	51.20	48.34	45.27	42.19
50	54.49	51.61	48.74	45.64	42.54
51	54.92	52.03	49.13	46.01	42.89
52	55.35	52.44	49.53	46.39	43.25
53	55.78	52.85	49.92	46.76	43.60
54	56.21	53.26	50.32	47.13	43.95
55	56.64	53.68	50.71	47.50	44.30
56	57.07	54.09	51.11	47.88	44.65
57	57.50	54.50	51.50	48.25	45.00
58	57.93	54.91	51.89	48.62	45.35
59	58.36	55.32	52.29	49.00	45.70
60	58.79	55.74	52.68	49.37	46.05

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR					120 FOOT POLE—con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
61	59.22	56.15	53.08	49.74	46.40
62	59.65	56.56	53.47	50.11	46.75
63	60.08	56.97	53.87	50.49	47.11
64	60.51	57.39	54.26	50.86	47.46
65	60.94	57.80	54.66	51.23	47.81
66	61.37	58.21	55.05	51.61	48.16
67	61.80	58.62	55.45	51.98	48.51
68	62.23	59.04	55.84	52.35	48.86
69	62.66	59.45	56.24	52.72	49.21
70	63.09	59.86	56.63	53.10	49.56
71	63.52	60.27	57.03	53.47	49.91
72	63.95	60.68	57.42	53.84	50.26
73	64.38	61.10	57.82	54.21	50.61
74	64.81	61.51	58.21	54.59	50.96
75	65.24	61.92	58.61	54.96	51.32
76	65.67	62.33	59.00	55.33	51.67
77	66.10	62.75	59.39	55.71	52.02
78	66.53	63.16	59.79	56.08	52.37
79	66.96	63.57	60.18	56.45	52.72
80	67.39	63.98	60.58	56.82	53.07
81	67.82	64.39	60.97	57.20	53.42
82	68.25	64.81	61.37	57.57	53.77
83	68.68	65.22	61.76	57.94	54.12
84	69.11	65.63	62.16	58.32	54.47
85	69.54	66.04	62.55	58.69	54.82
86	69.96	66.46	62.95	59.06	55.18
87	70.39	66.87	63.34	59.43	55.53
88	70.82	67.28	63.74	59.81	55.88
89	71.25	67.69	64.13	60.18	56.23
90	71.68	68.11	64.53	60.55	56.58
91	72.11	68.52	64.92	60.93	56.93
92	72.54	68.93	65.32	61.30	57.28
93	72.97	69.34	65.71	61.67	57.63
94	73.40	69.75	66.11	62.04	57.98
95	73.83	70.17	66.50	62.42	58.33
96	74.26	70.58	66.89	62.79	58.68
97	74.69	70.99	67.29	63.16	59.04
98	75.12	71.40	67.68	63.54	59.39
99	75.55	71.82	68.08	63.91	59.74
100	75.98	72.23	68.47	64.28	60.09
101	76.41	72.64	68.87	64.65	60.44
102	76.84	73.05	69.26	65.03	60.79
103	77.27	73.46	69.66	65.40	61.14
104	77.70	73.88	70.05	65.77	61.49
105	78.13	74.29	70.45	66.14	61.84
106	78.56	74.70	70.84	66.52	62.19
107	78.99	75.11	71.24	66.89	62.54
-------------GROUND LINE (12 FEET, 0 INCHES)---------------					
108	79.42	75.53	71.63	67.26	62.89
109	79.85	75.94	72.03	67.64	63.25
110	80.28	76.35	72.42	68.01	63.60

Table B-4.–*Pole circumferences for western red cedar*–Continued

					120 FOOT POLE —con.
WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
111	80.71	76.76	72.82	68.38	63.95
112	81.14	77.18	73.21	68.75	64.30
113	81.57	77.59	73.61	69.13	64.65
114	82.00	78.00	74.00	69.50	65.00
115	82.43	78.41	74.39	69.87	65.35
116	82.86	78.82	74.79	70.25	65.70
117	83.29	79.24	75.18	70.62	66.05
118	83.72	79.65	75.58	70.99	66.40
119	84.15	80.06	75.97	71.36	66.75
120	84.58	80.47	76.37	71.74	67.11

					125 FOOT POLE
WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
TOP	33.00	31.00	29.00	27.00	25.00
1	33.42	31.40	29.39	27.37	25.34
2	33.84	31.81	29.77	27.73	25.69
3	34.26	32.21	30.16	28.10	26.03
4	34.68	32.61	30.55	28.46	26.38
5	35.10	33.02	30.93	28.83	26.72
6	35.52	33.42	31.32	29.19	27.07
7	35.94	33.82	31.71	29.56	27.41
8	36.36	34.23	32.09	29.92	27.76
9	36.78	34.63	32.48	30.29	28.10
10	37.20	35.03	32.87	30.66	28.45
11	37.62	35.44	33.25	31.02	28.79
12	38.04	35.84	33.64	31.39	29.13
13	38.46	36.24	34.03	31.75	29.48
14	38.88	36.65	34.41	32.12	29.82
15	39.30	37.05	34.80	32.48	30.17
16	39.72	37.45	35.18	32.85	30.51
17	40.14	37.86	35.57	33.21	30.86
18	40.56	38.26	35.96	33.58	31.20
19	40.98	38.66	36.34	33.95	31.55
20	41.40	39.07	36.73	34.31	31.89
21	41.82	39.47	37.12	34.68	32.24
22	42.24	39.87	37.50	35.04	32.58
23	42.66	40.28	37.89	35.41	32.92
24	43.08	40.68	38.28	35.77	33.27
25	43.50	41.08	38.66	36.14	33.61
26	43.92	41.49	39.05	36.50	33.96
27	44.34	41.89	39.44	36.87	34.30
28	44.76	42.29	39.82	37.24	34.65
29	45.18	42.70	40.21	37.60	34.99
30	45.61	43.10	40.60	37.97	35.34

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Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	125 FOOT POLE–con. CLASS 2 CIRC. INCHES
31	46.03	43.50	40.98	38.33	35.68
32	46.45	43.91	41.37	38.70	36.03
33	46.87	44.31	41.76	39.06	36.37
34	47.29	44.71	42.14	39.43	36.71
35	47.71	45.12	42.53	39.79	37.06
36	48.13	45.52	42.92	40.16	37.40
37	48.55	45.92	43.30	40.53	37.75
38	48.97	46.33	43.69	40.89	38.09
39	49.39	46.73	44.08	41.26	38.44
40	49.81	47.13	44.46	41.62	38.78
41	50.23	47.54	44.85	41.99	39.13
42	50.65	47.94	45.24	42.35	39.47
43	51.07	48.34	45.62	42.72	39.82
44	51.49	48.75	46.01	43.08	40.16
45	51.91	49.15	46.39	43.45	40.50
46	52.33	49.55	46.78	43.82	40.85
47	52.75	49.96	47.17	44.18	41.19
48	53.17	50.36	47.55	44.55	41.54
49	53.59	50.76	47.94	44.91	41.88
50	54.01	51.17	48.33	45.28	42.23
51	54.43	51.57	48.71	45.64	42.57
52	54.85	51.97	49.10	46.01	42.92
53	55.27	52.38	49.49	46.37	43.26
54	55.69	52.78	49.87	46.74	43.61
55	56.11	53.18	50.26	47.11	43.95
56	56.53	53.59	50.65	47.47	44.29
57	56.95	53.99	51.03	47.84	44.64
58	57.37	54.39	51.42	48.20	44.98
59	57.79	54.80	51.81	48.57	45.33
60	58.21	55.20	52.19	48.93	45.67
61	58.63	55.61	52.58	49.30	46.02
62	59.05	56.01	52.97	49.66	46.36
63	59.47	56.41	53.35	50.03	46.71
64	59.89	56.82	53.74	50.39	47.05
65	60.31	57.22	54.13	50.76	47.39
66	60.73	57.62	54.51	51.13	47.74
67	61.15	58.03	54.90	51.49	48.08
68	61.57	58.43	55.29	51.86	48.43
69	61.99	58.83	55.67	52.22	48.77
70	62.41	59.24	56.06	52.59	49.12
71	62.83	59.64	56.45	52.95	49.46
72	63.25	60.04	56.83	53.32	49.81
73	63.67	60.45	57.22	53.68	50.15
74	64.09	60.85	57.61	54.05	50.50
75	64.51	61.25	57.99	54.42	50.84
76	64.93	61.66	58.38	54.78	51.18
77	65.35	62.06	58.76	55.15	51.53
78	65.77	62.46	59.15	55.51	51.87
79	66.19	62.87	59.54	55.88	52.22
80	66.61	63.27	59.92	56.24	52.56

Table B-4.–*Pole circumferences for western red cedar*–Continued

WESTERN RED CEDAR					125 FOOT POLE–con.
DISTANCE FROM TOP FEET	CLASS H-3 CIRC. INCHES	CLASS H-2 CIRC. INCHES	CLASS H-1 CIRC. INCHES	CLASS 1 CIRC. INCHES	CLASS 2 CIRC. INCHES
81	67.03	63.67	60.31	56.61	52.91
82	67.45	64.08	60.70	56.97	53.25
83	67.87	64.48	61.08	57.34	53.60
84	68.29	64.88	61.47	57.71	53.94
85	68.71	65.29	61.86	58.07	54.29
86	69.13	65.69	62.24	58.44	54.63
87	69.55	66.09	62.63	58.80	54.97
88	69.97	66.50	63.02	59.17	55.32
89	70.39	66.90	63.40	59.53	55.66
90	70.82	67.30	63.79	59.90	56.01
91	71.24	67.71	64.18	60.26	56.35
92	71.66	68.11	64.56	60.63	56.70
93	72.08	68.51	64.95	61.00	57.04
94	72.50	68.92	65.34	61.36	57.39
95	72.92	69.32	65.72	61.73	57.73
96	73.34	69.72	66.11	62.09	58.08
97	73.76	70.13	66.50	62.46	58.42
98	74.18	70.53	66.88	62.82	58.76
99	74.60	70.93	67.27	63.19	59.11
100	75.02	71.34	67.66	63.55	59.45
101	75.44	71.74	68.04	63.92	59.80
102	75.86	72.14	68.43	64.29	60.14
103	76.28	72.55	68.82	64.65	60.49
104	76.70	72.95	69.20	65.02	60.83
105	77.12	73.35	69.59	65.38	61.18
106	77.54	73.76	69.97	65.75	61.52
107	77.96	74.16	70.36	66.11	61.87
108	78.38	74.56	70.75	66.48	62.21
109	78.80	74.97	71.13	66.84	62.55
110	79.22	75.37	71.52	67.21	62.90
111	79.64	75.77	71.91	67.58	63.24
112	80.06	76.18	72.29	67.94	63.59
------------GROUND LINE (12 FEET, 0 INCHES)--------------					
113	80.48	76.58	72.68	68.31	63.93
114	80.90	76.98	73.07	68.67	64.28
115	81.32	77.39	73.45	69.04	64.62
116	81.74	77.79	73.84	69.40	64.97
117	82.16	78.19	74.23	69.77	65.31
118	82.58	78.60	74.61	70.13	65.66
119	83.00	79.00	75.00	70.50	66.00
120	83.42	79.40	75.39	70.87	66.34
121	83.84	79.81	75.77	71.23	66.69
122	84.26	80.21	76.16	71.60	67.03
123	84.68	80.61	76.55	71.96	67.38
124	85.10	81.02	76.93	72.33	67.72
125	85.52	81.42	77.32	72.69	68.07

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Table B-5.–*Permanent set values for Alumoweld strand*

Maximum conductor tension Percent of rated strength	Permanent set mm/mm or in/in	Maximum conductor tension Percent of rated strength	Permanent set mm/mm or in/in
10	0.000 096	40	0.000 502
11	.000 104	41	.000 521
12	.000 112	42	.000 540
13	.000 120	43	.000 559
14	.000 129	44	.000 579
15	.000 138	45	.000 600
16	.000 148	46	.000 622
17	.000 159	47	.000 645
18	.000 171	48	.000 668
19	.000 183	49	.000 691
20	.000 195	50	.000 714
21	.000 206	51	.000 737
22	.000 217	52	.000 760
23	.000 228	53	.000 783
24	.000 240	54	.000 807
25	.000 253	55	.000 832
26	.000 267	56	.000 858
27	.000 282	57	.000 885
28	.000 298	58	.000 912
29	.000 314	59	.000 940
30	.000 330	60	.000 968
31	.000 347	61	.000 997
32	.000 364	62	.001 027
33	.000 381	63	.001 057
34	.000 398	64	.001 087
35	.000 415	65	.001 118
36	.000 432	66	.001 149
37	.000 449	67	.001 181
38	.000 466	68	.001 214
39	.000 484	69	.001 248
		70	.001 283

Initial modulus: 148.238 GPa (21.5×10^6 lb/in^2)
Final modulus: 158.580 GPa (23×10^6 lb/in^2)

Table B-6.–*Permanent set values for steel strand*

Tension		10 mm (3/8 in)		11 mm (7/16 in)		13 mm ([illegible]2 in)	
N	lb	HS[1]	EHS[2]	HS[1]	EHS[2]	HS[1]	EHS[2]
8 896	2 000	0.000 136	0.000 036	0.000 091	0.000 019	0.000 060	0.000 012
9 341	2 100	.000 142	.000 037	.000 096	.000 020	.000 063	.000 013
9 786	2 200	.000 147	.000 038	.000 100	.000 021	.000 066	.000 014
10 231	2 300	.000 154	.000 039	.000 105	.000 022	.000 070	.000 015
10 657	2 400	.000 162	.000 040	.000 110	.000 023	.000 074	.000 016
11 121	2 500	.000 170	.000 041	.000 115	.000 024	.000 078	.000 017
11 565	2 600	.000 179	.000 042	.000 120	.000 025	.000 082	.000 018
12 010	2 700	.000 188	.000 043	.000 125	.000 026	.000 086	.000 019
12 455	2 800	.000 198	.000 045	.000 130	.000 027	.000 090	.000 020
12 900	2 900	.000 208	.000 047	.000 135	.000 028	.000 094	.000 021
13 345	3 000	.000 219	.000 049	.000 140	.000 029	.000 098	.000 022
13 789	3 100	.000 230	.000 052	.000 145	.000 030	.000 102	.000 023
14 234	3 200	.000 242	.000 055	.000 150	.000 031	.000 106	.000 024
14 679	3 300	.000 253	.000 058	.000 155	.000 032	.000 111	.000 025
15 124	3 400	.000 264	.000 061	.000 160	.000 033	.000 115	.000 026
15 569	3 500	.000 275	.000 064	.000 165	.000 034	.000 119	.000 027
16 014	3 600	.000 287	.000 068	.000 170	.000 035	.000 123	.000 028
16 458	3 700	.000 299	.000 072	.000 175	.000 036	.000 127	.000 029
16 903	3 800	.000 311	.000 076	.000 180	.000 037	.000 131	.000 030
17 348	3 900	.000 323	.000 081	.000 185	.000 038	.000 135	.000 031
17 793	4 000	.000 336	.000 086	.000 190	.000 040	.000 139	.000 032
18 238	4 100	.000 350	.000 092	.000 195	.000 041	.000 143	.000 033
18 682	4 200	.000 365	.000 098	.000 202	.000 043	.000 148	.000 034
19 127	4 300	.000 381	.000 104	.000 208	.000 045	.000 152	.000 035
19 572	4 400	.000 398	.000 110	.000 214	.000 047	.000 156	.000 036
20 017	4 500	.000 416	.000 117	.000 220	.000 049	.000 160	.000 037
20 462	4 600	.000 435	.000 124	.000 227	.000 051	.000 164	.000 038
20 907	4 700	.000 455	.000 131	.000 234	.000 053	.000 168	.000 039
21 351	4 800	.000 475	.000 138	.000 242	.000 056	.000 172	.000 040
21 796	4 900	.000 496	.000 146	.000 250	.000 058	.000 176	.000 041
22 241	5 000	.000 519	.000 154	.000 259	.000 062	.000 180	.000 042
22 686	5 100	.000 544	.000 162	.000 268	.000 065	.000 185	.000 043
23 131	5 200	.000 571	.000 171	.000 277	.000 068	.000 190	.000 044
23 575	5 300	.000 600	.000 180	.000 286	.000 071	.000 195	.000 045
24 020	5 400	.000 631	.000 189	.000 295	.000 074	.000 200	.000 046
24 465	5 500		.000 199	.000 305	.000 077	.000 205	.000 047
24 910	5 600		.000 209	.000 315	.000 080	.000 210	.000 048
25 355	5 700		.000 219	.000 325	.000 083	.000 215	.000 049
25 800	5 800		.000 230	.000 335	.000 086	.000 220	.000 050
26 244	5 900		.000 241	.000 347	.000 089	.000 225	.000 051
26 689	6 000		.000 252	.000 359	.000 092	.000 230	.000 052
27 134	6 100		.000 263	.000 371	.000 095	.000 236	.000 053
27 576	6 200		.000 275	.000 382	.000 099	.000 243	.000 054
28 024	6 300		.000 287	.000 393	.000 103	.000 250	.000 056
28 468	6 400		.000 299	.000 405	.000 107	.000 257	.000 058
28 913	6 500		.000 311	.000 417	.000 111	.000 264	.000 060
29 358	6 600		.000 324	.000 429	.000 115	.000 271	.000 062
29 803	6 700		.000 337	.000 441	.000 119	.000 278	.000 064
30 248	6 800		.000 351	.000 453	.000 123	.000 285	.000 067
30 693	6 900		.000 365	.000 465	.000 128	.000 292	.000 070

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Table B-6.–*Permanent set values for steel strand*–Continued

Tension		10 mm (3/8 in)		11 mm (7/16 in)		13 mm (1/2 in)	
N	lb	HS[1]	EHS[2]	HS[1]	EHS[2]	HS[1]	EHS[2]
31 137	7 000		0.000 380	0.000 477	0.000 133	0.000 299	0.000 073
31 582	7 100		.000 396	.000 489	.000 139	.000 306	.000 075
32 027	7 200		.000 413	.000 501	.000 146	.000 313	.000 078
32 472	7 300		.000 431	.000 513	.000 152	.000 320	.000 081
32 917	7 400		.000 451		.000 159	.000 327	.000 083
33 362	7 500		.000 472		.000 165	.000 334	.000 085
33 806	7 600		.000 493		.000 172	.000 341	.000 087
34 251	7 700		.000 515		.000 178	.000 348	.000 090
34 696	7 800				.000 185	.000 355	.000 093
35 141	7 900				.000 191	.000 363	.000 096
35 586	8 000				.000 198	.000 371	.000 099
36 030	8 100				.000 204	.000 378	.000 102
36 475	8 200				.000 211	.000 387	.000 105
36 920	8 300				.000 217	.000 396	.000 108
37 365	8 400				.000 224	.000 405	.000 111
37 810	8 500				.000 230	.000 414	.000 114
38 255	8 600				.000 237	.000 424	.000 118
38 699	8 700				.000 243	.000 434	.000 122
39 144	8 800				.000 249	.000 444	.000 126
39 589	8 900				.000 256	.000 454	.000 130
40 034	9 000				.000 262	.000 464	.000 135
40 479	9 100				.000 268	.000 474	.000 139
40 923	9 200				.000 274	.000 484	.000 143
41 368	9 300				.000 280	.000 495	.000 147
41 813	9 400				.000 287	.000 506	.000 151
42 258	9 500				.000 295		.000 155
42 703	9 600				.000 306		.000 159
43 148	9 700				.000 318		.000 164
43 592	9 800				.000 329		.000 168
44 037	9 900				.000 341		.000 173
44 482	10 000				.000 352		.000 178
44 927	10 100				.000 364		.000 183
45 372	10 200				.000 375		.000 188
45 816	10 300				.000 387		.000 192
46 261	10 400				.000 403		.000 197
46 706	10 500						.000 201
47 151	10 600						.000 205
47 596	10 700						.000 209
48 041	10 800						.000 213
48 485	10 900						.000 218
48 930	11 000						.000 223
49 375	11 100						.000 228
49 820	11 200						.000 233
50 265	11 300						.000 238
50 709	11 400						.000 243
51 154	11 500						.000 249
51 599	11 600						.000 255
52 044	11 700						.000 261
52 489	11 800						.000 267
52 934	11 900						.000 273

Table B-6.–*Permanent set values for steel strand*–Continued

Tension		10 mm (3/8 in)		11 mm (7/16 in)		13 mm (1/2 in)	
N	lb	HS[1]	EHS[2]	HS[1]	EHS[2]	HS[1]	EHS[2]
53 378	12 000						0.000 280
53 823	12 100						.000 287
54 268	12 200						.000 295
54 713	12 300						.000 302
55 158	12 400						.000 309
55 603	12 500						.000 317
56 047	12 600						.000 325
56 492	12 700						.000 333
56 937	12 800						.000 341
57 382	12 900						.000 350
57 827	13 000						.000 359
58 271	13 100						.000 368
58 716	13 200						.000 377
59 161	13 300						.000 386
59 606	13 400						.000 396
Ultimate strength		48 040 N (10 800 lb)	68 500 N (15 400 lb)	64 500 N (14 500 lb)	92 520 N (20 800 lb)	83 625 N (18 800 lb)	119 655 N (26 900 lb)

[1] High strength. Initial modulus = 158.580 GPa (23 x 10^6 lb/in^2). Final modulus = 177.885 GPa (25.8 x 10^6 lb/in^2).

[2] Extra-high strength. Initial modulus = 162.028 GPa (23.5 x 10^6 lb/in^2). Final modulus = 177.885 GPa (25.8 x 10^6 lb/in^2).

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Table B-7.–*Flashover characteristics of suspension insulator strings and air gaps*

Impulse air gap,		Impulse flashover (positive critical),	Number of insulator units[1]	Wet 60-Hz flashover,	Wet 60-Hz air gap,	
in	mm	kV		kV	mm	in
8	203	150	1	50	254	10
14	356	255	2	90	305	12
21	533	355	3	130	406	16
26	660	440	4	170	508	20
32	813	525	5	215	660	26
38	965	610	6	255	762	30
43	1092	695	7	295	889	35
49	1245	780	8	335	991	39
55	1397	860	9	375	1118	44
60	1524	945	10	415	1245	49
66	1676	1025	11	455	1346	53
71	1803	1105	12	490	1473	58
77	1956	1185	13	525	1575	62
82	2083	1265	14	565	1676	66
88	2235	1345	15	600	1778	70
93	2362	1425	16	630	1880	74
99	2515	1505	17	660	1981	78
104	2642	1585	18	690	2083	82
110	2794	1665	19	720	2184	86
115	2921	1745	20	750	2286	90
121	3073	1825	21	780	2388	94
126	3200	1905	22	810	2464	97
132	3353	1985	23	840	2565	101
137	3480	2065	24	870	2692	106
143	3632	2145	25	900	2794	110
148	3759	2225	26	930	2921	115
154	3912	2305	27	960	3023	119
159	4039	2385	28	990	3124	123
165	4191	2465	29	1020	3251	128
171	4343	2550	30	1050	3353	132

[1] Insulator units are 146 by 254 mm (5-3/4 by 10 in) or 146 by 267 mm (5-3/4 by 10-1/2 in).

Table B-8.–*Flashover values of air gaps*

Air gap		Flashover		Air gap		Flashover	
mm	in	60-Hz wet, kV	Pos. critical impulse, kV	mm	in	60-Hz wet, kV	Pos. critical impulse, kV
25	1		38	1295	51	438	814
51	2		60	1321	52	447	829
76	3		75	1346	53	455	843
102	4		91-95	1372	54	464	858
127	5		106-114	1397	55	472	872
152	6		128-141	1422	56	481	887
178	7		141-155	1448	57	489	901
203	8		159-166	1473	58	498	916
229	9		175-178	1499	59	506	930
254	10	80	190	1524	60	515	945
279	11	89	207	1549	61	523	960
305	12	98	224	1575	62	532	975
330	13	107	241	1600	63	540	990
356	14	116	258	1626	64	549	1005
381	15	125	275	1651	65	557	1020
406	16	134	290	1676	66	566	1035
432	17	143	305	1702	67	574	1050
457	18	152	320	1727	68	583	1065
483	19	161	335	1753	69	591	1080
508	20	170	350	1778	70	600	1095
533	21	178	365	1803	71	607	1109
559	22	187	381	1829	72	615	1124
584	23	195	396	1854	73	622	1138
610	24	204	412	1880	74	630	1153
635	25	212	427	1905	75	637	1167
660	26	221	443	1930	76	645	1182
686	27	229	458	1956	77	652	1196
711	28	238	474	1981	78	660	1211
737	29	246	489	2007	79	667	1225
762	30	255	505	2032	80	675	1240
787	31	264	519	2057	81	683	1254
813	32	273	534	2083	82	691	1269
838	33	282	548	2108	83	699	1283
864	34	291	563	2134	84	707	1298
889	35	300	577	2159	85	715	1312
914	36	309	592	2184	86	723	1327
940	37	318	606	2210	87	731	1341
965	38	327	621	2235	88	739	1356
991	39	336	635	2261	89	747	1370
1016	40	345	650	2286	90	755	1385
1041	41	353	665	2311	91	763	1399
1067	42	362	680	2337	92	771	1414
1092	43	370	695	2362	93	779	1428
1118	44	379	710	2388	94	787	1443
1143	45	387	725	2413	95	795	1457
1168	46	396	740	2438	96	803	1472
1194	47	404	755	2464	97	811	1486
1219	48	413	770	2489	98	819	1501
1245	49	421	785	2515	99	827	1515
1270	50	430	800	2540	100	835	1530

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Table B-8.–*Flashover values of air gaps*–Continued

Air gap		Flashover		Air gap		Flashover	
mm	in	60-Hz wet, kV	Pos. critical impulse, kV	mm	in	60-Hz wet, kV	Pos. critical impulse, kV
2565	101	842	1544	3835	151	1176	2269
2591	102	848	1559	3861	152	1182	2284
2616	103	855	1573	3886	153	1188	2298
2642	104	862	1588	3912	154	1194	2313
2667	105	869	1602	3937	155	1200	2327
2692	106	875	1617	3962	156	1206	2342
2718	107	882	1631	3988	157	1212	2356
2743	108	889	1646	4013	158	1218	2371
2769	109	896	1660	4039	159	1224	2385
2794	110	902	1675	4064	160	1230	2400
2819	111	909	1689	4089	161	1236	2414
2845	112	916	1704	4115	162	1242	2429
2870	113	923	1718	4140	163	1248	2443
2896	114	929	1733	4166	164	1254	2458
2921	115	936	1747	4191	165	1260	2472
2946	116	943	1762	4216	166	1266	2487
2972	117	950	1776	4242	167	1272	2501
2997	118	956	1791	4267	168	1278	2516
3023	119	963	1805	4293	169	1284	2530
3048	120	970	1820	4318	170	1290	2545
3073	121	977	1834	4343	171	1296	2559
3099	122	984	1849	4369	172	1302	2574
3124	123	991	1863	4394	173	1308	2588
3150	124	998	1878	4420	174	1314	2603
3175	125	1005	1892	4445	175	1320	2617
3200	126	1012	1907	4470	176	1326	2632
3226	127	1019	1921	4496	177	1332	2646
3251	128	1026	1936	4521	178	1338	2661
3277	129	1033	1950	4547	179	1344	2675
3302	130	1040	1965	4572	180	1350	2690
3327	131	1047	1979	4597	181	1355	2704
3353	132	1054	1994	4623	182	1361	2719
3378	133	1061	2008	4648	183	1366	2733
3404	134	1068	2023	4674	184	1372	2748
3429	135	1075	2037	4699	185	1377	2762
3454	136	1082	2052	4724	186	1383	2777
3480	137	1089	2066	4750	187	1388	2791
3505	138	1096	2081	4775	188	1394	2806
3531	139	1103	2095	4801	189	1399	2820
3556	140	1110	2110	4826	190	1405	2835
3581	141	1116	2124	4851	191	1410	2849
3607	142	1122	2139	4877	192	1416	2864
3632	143	1128	2153	4902	193	1421	2878
3658	144	1134	2168	4928	194	1427	2893
3683	145	1140	2182	4953	195	1432	2907
3708	146	1146	2197	4978	196	1438	2922
3734	147	1152	2211	5004	197	1443	2936
3759	148	1158	2226	5029	198	1449	2951
3785	149	1164	2240	5055	199	1454	2965
3810	150	1170	2255	5080	200	1460	2980

Table B-9.–*Relative air density and barometric pressure*

Elevation		Barometric pressure		Relative air density	
m	ft	mm	in	at 25 °C	at 77 °F
0	0	760	29.92	1.00	1.00
328.08	1 000	733	28.86	0.96	0.96
656.17	2 000	707	27.82	.93	.93
984.25	3 000	681	26.81	.90	.90
1312.34	4 000	656	25.84	.86	.86
1640.42	5 000	632	24.89	.83	.83
1968.50	6 000	609	23.98	.80	.80
2296.59	7 000	587	23.10	.77	.77
2624.67	8 000	564	22.22	.74	.74
2952.76	9 000	544	21.40	.72	.72
3280.84	10 000	523	20.58	.69	.69
3608.92	11 000	503	19.81	.66	.66
3937.01	12 000	484	19.05	.64	.64
4265.09	13 000	465	18.31	.61	.61
4593.18	14 000	447	17.58	.59	.59
4921.26	15 000	429	16.88	.56	.56
5249.34	16 000	412	16.21	.54	.54

Table B-10.–*Barometric pressure versus elevation*

Non-standard air factor	Barometric pressure		Elevation		Non-standard air factor	Barometric pressure		Elevation	
	mm of mercury	inches of mercury [1]	m	ft		mm of mercury	inches of mercury [1]	m	ft
1.00	760	29.92	0	0	1.23	585	23.04	2154	7 068
1.01	752	29.62	85	280	1.24	578	22.74	2258	7 409
1.02	745	29.32	171	561	1.25	570	22.44	2362	7 750
1.03	737	29.02	256	841	1.26	562	22.14	2468	8 098
1.04	730	28.72	343	1126	1.27	555	21.84	2580	8 463
1.05	722	28.42	432	1417	1.28	547	21.54	2691	8 829
1.06	714	28.12	521	1709	1.29	540	21.24	2803	9 195
1.07	707	27.83	609	1999	1.30	532	20.94	2914	9 561
1.08	699	27.53	697	2287	1.31	524	20.64	3026	9 927
1.09	692	27.23	788	2584	1.32	517	20.35	3139	10 299
1.10	684	26.93	878	2881	1.33	509	20.05	3258	10 688
1.11	676	26.63	971	3186	1.34	502	19.75	3377	11 079
1.12	669	26.33	1065	3495	1.35	494	19.45	3497	11 474
1.13	661	26.03	1159	3804	1.36	486	19.15	3617	11 868
1.14	654	25.73	1253	4112	1.37	479	18.85	3740	12 270
1.15	646	25.43	1347	4418	1.38	471	18.55	3864	12 676
1.16	638	25.13	1440	4724	1.39	464	18.25	3987	13 082
1.17	631	24.83	1534	5034	1.40	456	17.95	4113	13 493
1.18	623	24.53	1638	5375	1.41	448	17.65	4238	13 904
1.19	616	24.24	1739	5705	1.42	441	17.35	4369	14 333
1.20	608	23.94	1843	6045	1.43	433	17.05	4501	14 768
1.21	600	23.64	1946	6386	1.44	426	16.76	4630	15 191
1.22	593	23.34	2050	6727	1.45	418	16.46	4765	15 632

[1] Barometric pressure = (29.92) (2 minus nonstandard air factor).

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Table B-11.—*Mass per unit volume and relative mass density of wood species used for poles*[1]

Species	Green		Air-dry (15 percent moisture content)		Relative mass density[2]
	kg/m³	lb/ft³	kg/m³	lb/ft³	
Bald cypress	801	50	512	32	0.42
Douglas-fir					
Coast type	625	39	545	34	.45
Rocky Mountain type	657	41	480	30	.40
Hemlock, western	657	41	464	29	.38
Larch, western	801	50	609	38	.51
Pine					
Jack	641	40	480	30	.40
Loblolly[3]	849	53	577	36	.47
Lodgepole	625	39	464	29	.38
Longleaf[3]	881	55	657	41	.54
Ponderosa	721	45	448	28	.38
Red	785	49	496	31	.41
Shortleaf[3]	833	52	561	35	.46
Red cedar					
Eastern	593	37	529	33	.44
Western	432	27	368	23	.31
Redwood	801	50	400	25	.38
Spruce (red, sitka, and white)	545	34	448	28	.37
White cedar					
Atlantic	400	25	368	23	.31
Northern	432	27	352	22	.29

[1] From "Wood Handbook," Forest Products Laboratory, U.S. Forest Service, Department of Agriculture.

[2] Based on volume when green, and mass when oven dry.

[3] Part of southern yellow pine group.

Volume of pole	
Metric	U.S. Customary
$V = 2.616 \times 10^{-7} h(d_1^2 + d_1 d_2)\mathrm{m}^3$	$V = 1.818 \times 10^{-3} h(d_1^2 + d_1 d_2)\mathrm{ft}^3$
where, h = length of pole, m	where, h = length of pole, ft
d_1 = diameter of pole at top, mm	d_1 = diameter of pole at top, in
d_2 = diameter of pole at bottom, mm	d_2 = diameter of pole at bottom, in

Table B-12.–*Conductor temperature coefficients of expansion for normal sag-tension computations*

Conductor	Stranding	Temperature coefficient of expansion Initial/°F x 10^{-6}	Final/°F x 10^{-6}	Initial/°C x 10^{-6}	Final/°C x 10^{-6}
EC aluminum	all	12.8	12.8	23.0	23.0
Steel	all	6.4	6.4	11.5	11.5
ACSR [1]	6/1	10.2	10.5	18.3	18.9
ACSR	7/1	9.5	9.8	17.1	17.7
ACSR	18/1	11.6	11.7	20.8	21.1
ACSR	24/7	10.5	10.8	18.9	19.5
ACSR	26/7	9.9	10.5	17.8	18.9
ACSR	30/7	9.5	9.9	17.0	17.8
ACSR	45/7	11.2	11.5	20.2	20.7
ACSR	54/7	10.2	10.7	18.3	19.3
ACSR	54/19	10.4	10.8	18.8	19.5
ACSR	84/19	11.2	11.5	20.1	20.6

[1] For ACSR conductors, the values shown apply only when the stress is borne by both the steel and aluminum strands.

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Table B-13.–*Pressure on a projected area due to wind velocity*

Indicated velocity		Actual velocity		Pressure on projected area			
				Cylindrical surface		Flat surface	
m/s	mi/h	m/s	mi/h	kPa	lb/ft^2	kPa	lb/ft^2
0.894	2	0.894	2.0	0.000 48	0.01	0.0008	0.02
1.788	4	1.743	3.9	.001 82	.04	.0031	.06
2.682	6	2.593	5.8	.004 03	.08	.0068	.14
3.576	8	3.442	7.7	.007 10	.15	.0119	.25
4.470	10	4.291	9.6	.011 03	.23	.0185	.39
5.364	12	5.006	11.2	.015 01	.31	.0252	.53
6.258	14	5.766	12.9	.019 91	.42	.0335	.70
7.152	16	6.482	14.5	.025 17	.53	.0423	.88
8.046	18	7.241	16.2	.031 41	.66	.0528	1.10
8.940	20	7.957	17.8	.037 92	.79	.0637	1.33
11.175	25	9.745	21.8	.056 88	1.19	.0956	2.00
13.410	30	11.488	25.7	.079 05	1.65	.1328	2.77
15.645	35	13.231	29.6	.104 86	2.19	.1762	3.68
17.880	40	14.930	33.4	.133 51	2.79	.2243	4.68
20.115	45	16.584	37.1	.164 73	3.44	.2768	5.78
22.350	50	18.238	40.8	.199 23	4.16	.3347	6.99
24.585	55	19.892	44.5	.237 01	4.95	.3982	8.32
26.820	60	21.500	48.1	.276 87	5.78	.4652	9.72
29.055	65	23.065	51.6	.318 65	6.66	.5353	11.18
31.290	70	24.630	55.1	.363 36	7.59	.6104	12.75
33.525	75	26.194	58.6	.410 97	8.58	.6904	14.42
35.760	80	27.893	62.4	.466 01	9.73	.7829	16.25
37.995	85	29.368	65.7	.516 60	10.79	.8679	18.13
40.230	90	30.977	69.3	.574 76	12.01	.9656	20.17
42.465	95	32.542	72.8	.634 30	13.25	1.0656	22.26
44.700	100	34.061	76.2	.694 90	14.52	1.1674	24.39
46.935	105	35.626	79.7	.760 22	15.88	1.2772	26.68
49.170	110	37.190	83.2	.828 43	17.31	1.3918	29.07
51.405	115	38.755	86.7	.899 62	18.79	1.5114	31.57
53.640	120	40.319	90.2	.973 70	20.34	1.6358	34.17
55.875	125	41.884	93.7	1.050 75	21.95	1.7653	36.87
58.110	130	43.448	97.2	1.130 69	23.62	1.8996	39.68
60.345	135	45.013	100.7	1.213 62	25.35	2.0389	42.59
62.580	140	46.622	104.3	1.301 93	27.20	2.1872	45.69
64.815	145	48.187	107.8	1.390 80	29.05	2.3365	48.81
67.050	150	49.751	111.3	1.482 55	30.97	2.4907	52.03
71.520	160	52.835	118.2	1.672 05	34.93	2.8090	58.68
75.990	170	55.964	125.2	1.875 96	39.19	3.1516	65.84
80.460	180	59.093	132.2	2.091 59	43.69	3.5139	73.40
84.930	190	62.178	139.1	2.315 68	48.37	3.8903	81.26

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Table B-14.–*Equivalent metric data for standard electrical conductors*

		U.S. Customary					Metric		
		Size of conductor			Area, in^2			Area, mm^2	
Code word	Stranding	AWG No.	Thousand circular mils (kcmil)	Diameter, in	Aluminum	Total	Diameter, mm	Aluminum	Total
Turkey	6/1	6		0.198	0.0206	0.0240	5.03	13.29	15.48
Swan	6/1	4		0.250	0.0328	0.0383	6.35	21.16	24.71
Sparrow	6/1	2		0.316	0.0521	0.0608	8.03	33.61	39.23
Robin	6/1	1		0.355	0.0657	0.0767	9.02	42.39	49.48
Raven	6/1	1/0		0.398	0.0829	0.0967	10.11	53.48	62.39
Quail	6/1	2/0		0.447	0.1045	0.1219	11.35	67.42	78.65
Pigeon	6/1	3/0		0.502	0.1318	0.1538	12.75	85.03	99.23
Penguin	6/1	4/0		0.563	0.1662	0.1939	14.30	107.23	125.10
Partridge	26/7		266.8	0.642	0.2095	0.2436	16.31	135.16	157.16
Ostrich	26/7		300.0	0.680	0.2356	0.2740	17.27	152.00	176.77
Linnet	26/7		336.4	0.721	0.2642	0.3072	18.31	170.45	198.19
Ibis	26/7		397.5	0.783	0.3122	0.3630	19.89	201.42	234.19
Lark	30/7		397.5	0.806	0.3122	0.3850	20.47	201.42	248.39
Flicker	24/7		477.0	0.846	0.3746	0.4232	21.49	241.68	273.03
Hawk	26/7		477.0	0.858	0.3746	0.4356	21.79	241.68	281.03
Parakeet	24/7		556.5	0.914	0.4371	0.4938	23.22	282.00	318.58
Dove	26/7		556.5	0.927	0.4371	0.5083	23.55	282.00	327.93
Peacock	24/7		605.0	0.953	0.4752	0.5368	24.21	306.58	346.32
Squab	26/7		605.0	0.966	0.4752	0.5526	24.54	306.58	356.52
Rook	24/7		636.0	0.977	0.4955	0.5643	24.82	322.26	364.06
Grosbeak	26/7		636.0	0.990	0.4995	0.5809	25.15	322.26	374.77
Flamingo	24/7		666.0	1.000	0.5235	0.5914	25.40	337.74	381.55
Drake	26/7		795.0	1.108	0.6244	0.7261	28.14	402.84	468.45
Tern	45/7		795.0	1.063	0.6244	0.6676	27.00	402.84	430.71
Rail	45/7		954.0	1.165	0.7493	0.8011	29.59	483.42	516.84
Cardinal	54/7		954.0	1.196	0.7493	0.8464	30.38	483.42	546.06
Ortolan	45/7		1033.5	1.213	0.8117	0.8678	30.81	523.68	559.87
Curlew	54/7		1033.5	1.246	0.8117	0.9169	31.65	523.68	591.55
Bluejay	45/7		1113.0	1.259	0.8741	0.9346	31.98	563.93	602.97
Finch	54/19		1113.0	1.293	0.8741	0.9849	32.84	563.93	635.42
Bittern	45/7		1272.0	1.345	0.9990	1.068	34.16	644.51	689.03
Pheasant	54/19		1272.0	1.382	0.9990	1.126	35.10	644.51	726.45
Bobolink	45/7		1431.0	1.427	1.124	1.202	36.25	725.16	775.48
Plover	54/19		1431.0	1.465	1.124	1.266	37.21	725.16	816.77
Lapwing	45/7		1590.0	1.502	1.249	1.335	38.15	805.80	861.29
Falcon	54/19		1590.0	1.545	1.249	1.407	39.24	805.80	907.74
Chukar	84/19		1780.0	1.602	1.398	1.512	40.69	901.93	975.48
Bluebird	84/19		2156.0	1.762	1.693	1.831	44.75	1092.26	1181.29
Kiwi	72/7		2167.0	1.737	1.702	1.776	44.12	1098.06	1145.80

Table B-15.–*Selected SI-metric conversions. From [20]*

Area

To convert from	To	Multiply by	
acre [U.S. survey]	square meter (m^2)	4.046 873	E+03
are	square meter (m^2)	*1.000	E+02
barn	square meter (m^2)	*1.000	E-28
circular mil (cmil)	square meter (m^2)	5.067 075	E-10
hectare (ha)	square meter (m^2)	*1.000	E+04
section [U.S. survey]	square meter (m^2)	2.589 998	E+06
square centimeter (cm^2)	square meter (m^2)	*1.000	E-04
square chain	square meter (m^2)	*1.562 500	E-04
square foot [International] (ft^2)	square meter (m^2)	*9.290 304	E-02
square foot [U.S. survey] (ft^2)	square meter (m^2)	9.290 341	E-02
square inch (in^2)	square meter (m^2)	*6.451 600	E-04
square kilometer (km^2)	square meter (m^2)	*1.000	E+06
square mile [International] (mi^2)	square meter (m^2)	2.589 988	E+06
square mile [U.S. survey] (mi^2)	square meter (m^2)	2.589 998	E+06
square rod [U.S. survey] (rod^2)	square meter (m^2)	2.529 295	E+01
square yard (yd^2)	square meter (m^2)	8.361 274	E-01
township	square meter (m^2)	9.323 993	E+07

* Exact conversion.

Force

To convert from	To	Multiply by	
crinal	newton (N)	*1.000	E-01
dyne (dyn)	newton (N)	*1.000	E-05
kilogram force (kgf)	newton (N)	*9.806 650	
kilopond	newton (N)	*9.806 650	
kip	newton (N)	4.448 222	E+03
ounce force	newton (N)	2.780 139	E-01
pound force (lbf)	newton (N)	4.448 222	
poundal (pdl)	newton (N)	1.382 550	E-01
ton force	newton (N)	8.896 444	E+03

* Exact conversion.

Force per length

To convert from	To	Multiply by	
dyne per centimeter (dyn/cm)	newton per meter (N/m)	*1.000	E-03
kilogram force per meter (kgf/m)	newton per meter (N/m)	*9.806 650	
pound per foot (lb/ft)	newton per meter (N/m)	1.459 390	E+01
pound per inch (lb/in)	newton per meter (N/m)	1.751 268	E+02

* Exact conversion.

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Table B-15.—*Selected SI-metric conversions*—Continued

Density—Mass capacity

To convert from	To	Multiply by	
gram per cubic centimeter (g/cm^3)	kilogram per cubic meter (kg/m^3)	*1.000	E+03
gram per liter (g/L)	kilogram per cubic meter (kg/m^3)	*1.000	
megagram per cubic meter (Mg/m^3)	kilogram per cubic meter (kg/m^3)	*1.000	E+03
metric ton per cubic meter (t/m^3)	kilogram per cubic meter (kg/m^3)	*1.000	E+03
milligram per liter (mg/L)	kilogram per cubic meter (kg/m^3)	*1.000	E-03
ounce per cubic inch (oz/in^3)	kilogram per cubic meter (kg/m^3)	1.729 994	E+03
ounce per gallon (oz/gal)	kilogram per cubic meter (kg/m^3)	7.489 152	
ounce per pint (oz/pt)	kilogram per cubic meter (kg/m^3)	9.361 440	E-01
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767 990	E+04
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601 846	E+01
pound per cubic yard (lb/yd^3)	kilogram per cubic meter (kg/m^3)	5.932 764	E-01
pound per gallon (lb/gal)	kilogram per cubic meter (kg/m^3)	1.198 264	E+02
slug per cubic foot ($slug/ft^3$)	kilogram per cubic meter (kg/m^3)	5.153 788	E+02
ton [short] per cubic yard (ton/yd^3)	kilogram per cubic meter (kg/m^3)	1.186 553	E+03

* Exact conversion.

Time

To convert from	To	Multiply by	
day [mean solar] (d)	second (s)	*8.640	E+04
day [sidereal]	second (s)	8.616 409	E+04
hour [mean solar] (hr)	second (s)	*3.600	E+03
hour [sidereal]	second (s)	3.590 170	E+03
minute [mean solar] (min)	second (s)	*6.000	E+01
minute [sidereal]	second (s)	5.983 617	E+01
month [mean calendar] (mo)	second (s)	*2.628	E+06
second [sidereal]	second (s)	9.972 696	E-01
week [7 days] (wk)	second (s)	*6.048	E+05
year [calendar] (a)	second (s)	*3.153 600	E+07
year [sidereal]	second (s)	3.155 815	E+07

* Exact conversion.

Table B-15.–*Selected SI-metric conversions*–Continued

Length

To convert from	To	Multiply by	
angstrom unit (Å)	meter (m)	*1.000	E-10
astronomical unit (AU)	meter (m)	1.495 979	E+11
caliber	meter (m)	*2.540	E-02
centimeter (cm)	meter (m)	*1.000	E-02
chain, surveyor's	meter (m)	2.011 680	E+01
chain, engineer's	meter (m)	*3.048	E+01
chain, nautical	meter (m)	4.572	
fathom	meter (m)	*1.828 800	
fermi [obsolete replaced by femtometer]	meter (m)	*1.000	E-15
femtometer (fm)	meter (m)	*1.000	E-15
foot [U.S. survey] (ft)	meter (m)	3.048 006	E-01
foot [International] (ft)	meter (m)	*3.048	E-01
furlong (fur)	meter (m)	2.011 680	E+02
inch (in)	meter (m)	*2.540	E-02
kilometer (km)	meter (m)	*1.000	E+03
league	meter (m)	4.828 032	E-03
link, surveyor's	meter (m)	2.011 680	E-01
light year (ly)	meter (m)	9.460 900	E+15
microinch (μin)	meter (m)	*2.540	E-08
micrometer (μm)	meter (m)	*1.000	E-06
micron [obsolete, replaced by micrometer]	meter (m)	*1.000	E-06
mil (mil)	meter (m)	*2.540	E-05
mile [International] (mi)	meter (m)	*1.609 344	E+03
mile [Statute] (mi)	meter (m)	1.609 300	E+03
mile [U.S. survey] (mi)	meter (m)	1.609 347	E+03
nautical mile (nmi)	meter (m)	*1.852	E+03
parsec	meter (m)	3.085 678	E+16
pica, printer's	meter (m)	4.217 518	E-03
point, printer's	meter (m)	3.514 598	E-04
rod	meter (m)	5.029 210	
spat	meter (m)	*1.000	E+12
yard (yd)	meter (m)	*9.144	E-01

* Exact conversion.

Linear density

To convert from	To	Multiply by	
denier	kilogram per meter (kg/m)	1.111 111	E-07
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164	
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785 797	E+01
tex	kilogram per meter (kg/m)	*1.000	E-06

* Exact conversion.

Table B-15.–*Selected SI-metric conversions*–Continued

Load concentration

To convert from	To	Multiply by	
gram per square centimeter (g/cm^2)	kilogram per square meter (kg/m^2)	*1.000	E+01
megagram per square meter (Mg/m^2)	kilogram per square meter (kg/m^2)	*1.000	E+03
metric ton per square meter (t/m^2)	kilogram per square meter (kg/m^2)	*1.000	E+03
ounce per square inch (oz/in^2)	kilogram per square meter (kg/m^2)	2.119 109	E-03
ounce per square foot (oz/ft^2)	kilogram per square meter (kg/m^2)	3.051 517	E-01
ounce per square yard (oz/yd^2)	kilogram per square meter (kg/m^2)	3.390 575	E-02
pound per square inch (lb/in^2)	kilogram per square meter (kg/m^2)	7.030 696	E+02
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428	
pound per square yard (lb/yd^2)	kilogram per square meter (kg/m^2)	5.424 920	E-01
ton per square foot (ton/ft^2)	kilogram per square meter (kg/m^2)	9.071 847	E+02

* Exact conversion.

Power

To convert from	To	Multiply by	
British thermal unit [*IT*] per hour (Btu$_{IT}$/h)	watt (W)	2.930 711	E-01
British thermal unit [*tc*] per hour (Btu$_{tc}$/h)	watt (W)	2.928 751	E-01
British thermal unit [*tc*] per minute (Btu$_{tc}$/min)	watt (W)	1.757 250	E+01
British thermal unit [*tc*] per second (Btu$_{tc}$/s)	watt (W)	1.054 350	E+03
calorie [*tc*] per minute (cal$_{tc}$/min)	watt (W)	6.973 333	E-02
calorie [*tc*] per second (cal$_{tc}$/s)	watt (W)	*4.184	
erg per second (erg/s)	watt (W)	*1.000	E-07
foot-pound per hour (ft·lb/h)	watt (W)	3.766 161	E-04
foot-pound per minute (ft·lb/min)	watt (W)	2.259 697	E-02
foot-pound per second (ft·lb/s)	watt (W)	1.355 818	
horsepower (hp)	watt (W)	7.456 999	E+02
horsepower [boiler]	watt (W)	9.809 500	E+03
horsepower [electric]	watt (W)	*7.460	E+02
horsepower [metric] (hp$_M$)	watt (W)	7.354 990	E+02
horsepower [water]	watt (W)	7.460 430	E+02
ton [refrigeration]	watt (W)	3.516 800	E+03

* Exact conversion.

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Table B-15.—*Selected SI-metric conversions*—Continued

Mass

To convert from	To	Multiply by
barrel of cement [376 lb]	kilogram (kg)	1.705 507 E+02
carat [metric]	kilogram (kg)	*2.000 E-04
carat (kt)	kilogram (kg)	2.591 956 E-04
cental	kilogram (kg)	4.535 924 E+01
centner	kilogram (kg)	4.535 924 E+01
centner [metric]	kilogram (kg)	1.000 E+02[a]
grain	kilogram (kg)	6.479 891 E-05
gram (g)	kilogram (kg)	*1.000 E-03
hundredweight [gross or long] (cwt)	kilogram (kg)	5.080 235 E+01
hundredweight [net or short] (cwt)	kilogram (kg)	4.535 924 E+01
kilogram force—second squared per meter (kgf·s^2/m)	kilogram (kg)	*9.806 650
kilotonne (kt)	kilogram (kg)	*1.000 E+06
ounce [avoirdupois] (oz)	kilogram (kg)	2.834 952 E-02
ounce [troy/apothecary] (oz)	kilogram (kg)	3.110 348 E-02
megagram (Mg)	kilogram (kg)	*1.000 E+03
metric grain	kilogram (kg)	*5.000 E-05
metric ton (t)	kilogram (kg)	*1.000 E+03
milligram (mg)	kilogram (kg)	*1.000 E-06
pennyweight	kilogram (kg)	1.555 174 E-03
pound [avoirdupois] (lb)	kilogram (kg)	4.535 924 E-01
pound [troy/apothecary]	kilogram (kg)	3.732 417 E-01
quintal	kilogram (kg)	*1.000 E+02
sack of cement [94 lbs]	kilogram (kg)	4.263 767 E+01
slug	kilogram (kg)	1.459 390 E+01
ton [assay]	kilogram (kg)	2.916 667 E-02
ton [long]	kilogram (kg)	1.016 047 E+03
ton [short]	kilogram (kg)	9.071 847 E+02
tonne (t)	kilogram (kg)	*1.000 E+03

* Exact conversion.

[a] European metric centner is 50 percent of this value; conversion factor presented applies to the centner as used in the U.S.S.R.

Frequency

To convert from	To	Multiply by
cycle per hour (c/h)	hertz (Hz)	2.777 778 E-04
cycle per minute (c/min)	hertz (Hz)	1.666 667 E-02
cycle per second (c/s)	hertz (Hz)	*1.000
fresnel	hertz (Hz)	*1.000 E+12

* Exact conversion.

Table B-15.—*Selected SI-metric conversions*—Continued

Pressure—Stress

To convert from	To	Multiply by	
atmosphere [standard] (atm)	pascal (Pa)	1.013 250	E+05
bar	pascal (Pa)	*1.000	E+05
barye	pascal (Pa)	*1.000	E-01
dyne per square centimeter (dyn/cm^2)	pascal (Pa)	*1.000	E-01
foot of water [4 °C]	pascal (Pa)	2.988 980	E+03
gram force per square centimeter (gf/cm^2)	pascal (Pa)	*9.806 650	E+01
inch of mercury [0 °C]	pascal (Pa)	3.385 380	E+03
inch of mercury [16 °C]	pascal (Pa)	3.376 850	E+03
inch of water [4 °C]	pascal (Pa)	2.490 817	E+02
inch of water [16 °C]	pascal (Pa)	2.488 400	E+02
kilogram force per square meter (kgf/m^2)	pascal (Pa)	*9.806 650	
kilogram force per square centimeter (kgf/cm^2)	pascal (Pa)	*9.806 650	E+04
kip per square inch (kip/in^2)	pascal (Pa)	6.894 757	E+06
kip per square foot (kip/ft^2)	pascal (Pa)	4.788 026	E+04
megapascal (MPa)	pascal (Pa)	*1.000	E+06
meter-head [meter of water, 4 °C]	pascal (Pa)	9.806 365	E+03
millibar (mbar)	pascal (Pa)	*1.000	E+02
millimeter of mercury [0 °C] (mm(Hg))	pascal (Pa)	1.333 220	E+02
millimeter of water [4 °C] (mm(H_2O))	pascal (Pa)	9.806 365	
newton per square meter (N/m^2)	pascal (Pa)	*1.000	
pound per square foot (lb/ft^2)	pascal (Pa)	4.788 026	E+01
pound per square inch (lb/in^2)	pascal (Pa)	6.894 757	E+03
poundal per square foot (pdl/ft^2)	pascal (Pa)	1.488 164	
tor	pascal (Pa)	*1.000	
torr (mm(Hg))	pascal (Pa)	1.333 220	E+02

* Exact conversion.

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Table B-15.—*Selected SI-metric conversions*—Continued

Temperature

Scale values	Degrees Celsius °C	Degrees Fahrenheit °F	Kelvins K	Degrees Rankine °R	Degrees Reaumur °r
X °C =	–	$\frac{9}{5}X + 32$	$X + 273.15$	$\frac{9}{5}X + 491.67$	$\frac{4}{5}X$
X °F =	$\frac{5}{9}(X - 32)$	–	$\frac{5}{9}(X + 459.67)$	$X + 459.67$	$\frac{4}{9}(X - 32)$
X K =	$X - 273.15$	$\frac{9}{5}X - 459.67$	–	$\frac{9}{5}X$	$\frac{4}{5}(X - 273.15)$
X °R =	$\frac{5}{9}(X - 491.67)$	$X - 459.67$	$\frac{5}{9}X$	–	$\frac{4}{9}(X - 491.67)$
X °r =	$\frac{5}{4}X$	$\frac{9}{4}X + 32$	$\frac{5}{4}X + 273.15$	$\frac{9}{4}X + 491.67$	–

Intervals:

	°C	K	°F	°R	°r
1 °C = 1 K =	1		$\frac{9}{5}$		$\frac{4}{5}$
1 °F = 1 °R =	$\frac{5}{9}$		1		$\frac{4}{9}$
1 °r =	$\frac{5}{4}$		$\frac{9}{4}$		1

Table B-15.—*Selected SI-metric conversions*—Continued

Velocity—Speed

To convert from	To	Multiply by	
Angular (*θ/T*):			
degree per second	radian per second (rad/s)	1.745 329	E-02
revolution per minute (r/min)	radian per second (rad/s)	1.047 198	E-01
revolution per second (r/s)	radian per second (rad/s)	6.283 185	
Linear (*L/T*):			
foot per second (ft/s)	meter per second (m/s)	*3.048	E-01
foot per minute (ft/min)	meter per second (m/s)	*5.080	E-03
foot per hour (ft/h)	meter per second (m/s)	8.466 667	E-05
foot per day (ft/d)	meter per second (m/s)	3.527 778	E-06
foot per year (ft/a)	meter per second (m/s)	9.695 890	E-09
inch per second (in/s)	meter per second (m/s)	*2.540	E-02
inch per hour (in/h)	meter per second (m/s)	7.055 556	E-06
kilometer per hour (km/h)	meter per second (m/s)	2.777 778	E-01
knot [nautical miles per hour] (kn)	meter per second (m/s)	5.144 444	E-01
mile per hour (mi/h)	meter per second (m/s)	4.470 400	E-01
meter per hour (m/h)	meter per second (m/s)	2.777 778	E-04
meter per year (m/a)	meter per second (m/s)	3.170 979	E-08
millimeter per second (mm/s)	meter per second (m/s)	*1.000	E-03
speed of light (*c*)	meter per second (m/s)	2.997 925	E+08

* Exact conversion.

Torque—Bending moment

To convert from	To	Multiply by	
dyne centimeter (dyn·cm)	newton meter (N·m)	*1.000	E-07
kilogram force meter (kgf·m)	newton meter (N·m)	*9.806 650	
kip-foot (kip·ft)	newton meter (N·m)	1.355 818	E+02
ounce inch (oz·in)[a, b]	newton meter (N·m)	7.061 552	E-03
pound-foot (lb·ft)[a, b]	newton meter (N·m)	1.355 818	
pound-inch (lb·in)[a, b]	newton meter (N·m)	1.129 848	E-01

* Exact conversion.

[a] The addition of the force designator may be desirable, e.g., lbf·ft.

[b] Most USBR engineers reverse the torque units, for example, foot-pound; this is equivalent terminology.

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Table B-15.—*Selected SI-metric conversions*—Continued

Volume—Capacity

To convert from	To	Multiply by	
acre-foot [U.S. survey] (acre-ft)	cubic meter (m^3)	1.233 489	E+03
barrel [oil] (bbl)	cubic meter (m^3)	1.589 873	E-01
barrel [water] (bbl)	cubic meter (m^3)	1.192 405	E-01
board foot [1 ft x 1 ft x 1 in] (fbm)	cubic meter (m^3)	2.359 737	E-03
bushel [U.S., dry] (bu)	cubic meter (m^3)	3.523 907	E-02
cord	cubic meter (m^3)	3.624 556	
cubic centimeter (cm^3)	cubic meter (m^3)	*1.000	E-06
cubic decimeter (dm^3)	cubic meter (m^3)	*1.000	E-03
cubic dekameter (dam^3)	cubic meter (m^3)	*1.000	E+03
cubic foot (ft^3)	cubic meter (m^3)	2.831 685	E-02
cubic inch (in^3)	cubic meter (m^3)	1.638 706	E-05
cubic kilometer (km^3)	cubic meter (m^3)	*1.000	E+09
cubic mile (mi^3)	cubic meter (m^3)	4.168 182	E+09
cubic millimeter (mm^3)	cubic meter (m^3)	*1.000	E-09
cubic yard (yd^3)	cubic meter (m^3)	7.645 549	E-01
cup	cubic meter (m^3)	2.359 737	E-03
firkin	cubic meter (m^3)	3.406 871	E-02
fluid dram	cubic meter (m^3)	3.696 691	E-06
fluid ounce [U.S.] (fl.oz.)	cubic meter (m^3)	2.957 353	E-05
gallon [Imperial]	cubic meter (m^3)	4.546 060	E-03
gallon [U.S., dry]	cubic meter (m^3)	4.404 884	E-03
gallon [U.S., liquid] (gal)	cubic meter (m^3)	3.785 412	E-03
gill [U.S.]	cubic meter (m^3)	1.182 941	E-04
kiloliter (kL)	cubic meter (m^3)	*1.000	
liter (L)	cubic meter (m^3)	*1.000	E-03
megaliter (ML)	cubic meter (m^3)	*1.000	E+03
milliliter (mL)	cubic meter (m^3)	*1.000	E-06
peck [U.S.]	cubic meter (m^3)	8.809 768	E-03
pint [U.S., dry]	cubic meter (m^3)	5.506 105	E-04
pint [U.S., liquid]	cubic meter (m^3)	4.731 765	E-04
quart [U.S., dry]	cubic meter (m^3)	1.101 221	E-03
quart [U.S., liquid]	cubic meter (m^3)	9.463 529	E-04
stere [timber]	cubic meter (m^3)	*1.000	
tablespoon	cubic meter (m^3)	1.478 676	E-05
teaspoon	cubic meter (m^3)	4.928 922	E-06
ton [sea freight or shipping capacity]	cubic meter (m^3)	1.132 674	
ton [internal cap. of ships or register ton]	cubic meter (m^3)	2.831 685	
ton [vol. of oil]	cubic meter (m^3)	6.700 179	
ton [timber]	cubic meter (m^3)	1.415 842	
tun [U.S., liquid]	cubic meter (m^3)	9.539 238	E-01

* Exact conversion.

«Appendix C

CONDUCTOR AND OVERHEAD GROUND WIRE DATA TABLES

The tables in this appendix have been prepared for ACSR conductor based upon conductor data and stress-strain and creep curves prepared by the Aluminum Association. The Alumoweld data are based on information from Copperweld Steel Co., and the steel data are based on American Steel and Wire Co. (U.S. Steel) catalog information.

Initial modulus values shown in the tables were determined from the average slope of the initial loading curve between the point where the entire conductor starts to share the load and the point at 50 percent of the ultimate strength.

Permanent set values were determined at 50 percent of the conductor ultimate strength as it represents the maximum stress permitted under full load conditions.

Creep values were determined at 18 percent of the ultimate strength of the conductor because this would be about equal to the 15.5 °C (60 °F) final no-load tension on a conductor.

Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*

6 ALUMINUM STRANDS AND 1 STEEL STRAND				
Code word	**Size, mm²**	**10-year creep[1]**	**Tension[1], N**	**Final modulus, GPa**
TURKEY	13.28	.00046458	952.8	79.014
SWAN	21.13	.00045465	1489.3	79.014
SPARROW	33.64	.00043810	2281.9	79.014
ROBIN	42.41	.00043228	2842.4	79.014
RAVEN	53.46	.00042251	3507.0	79.014
QUAIL	67.44	.00040529	4251.6	79.014
PIGEON	85.02	.00040014	5300.5	79.014
PENGUIN	107.22	.00040034	6685.6	79.014

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00005034	
13.79	.00006347	68.679
20.68	.00007589	68.923
27.58	.00008791	69.099
34.47	.00009981	69.207
41.37	.00011190	69.245
48.26	.00012448	69.214
55.16	.00013784	69.116
62.05	.00015228	68.951
68.95	.00016810	68.721
75.84	.00018560	68.431
82.74	.00020507	68.082
89.63	.00022682	67.680
96.53	.00025114	67.227
103.42	.00027834	66.728
110.32	.00030870	66.187
117.21	.00034253	65.609
124.11	.00038012	64.998
131.00	.00042178	64.358
137.90	.00046780	63.694
144.79	.00051848	63.008
151.69	.00057412	62.306
158.58	.00063501	61.589
165.48	.00070146	60.861
172.37	.00077376	60.126
179.26	.00085221	59.385
186.16	.00093712	58.641
193.05	.00102877	57.897
199.95	.00112746	57.153
206.84	.00123350	56.412

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[1] Calculated at 18 percent of ultimate strength.

Table C-1.—*Permanent set, creep, and initial and final modulus values (metric)*—Continued

7 ALUMINUM STRANDS AND 1 STEEL STRAND

Code word	Size, mm^2	10-year creep[1]	Tension[1], N	Final modulus, GPa
SWANATE	21.13	.00048932	1889.6	87.012
SPARATE	33.64	.00047536	2914.5	87.012

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00002236	
13.79	.00003009	79.271
20.68	.00003766	79.351
27.58	.00004518	79.389
34.47	.00005282	79.383
41.37	.00006070	79.335
48.26	.00006896	79.244
55.16	.00007776	79.112
62.05	.00008723	78.939
68.95	.00009751	78.726
75.84	.00010874	78.474
82.74	.00012106	78.186
89.63	.00013462	77.862
96.53	.00014955	77.505
103.42	.00016600	77.115
110.32	.00018410	76.696
117.21	.00020401	76.249
124.11	.00022585	75.776
131.00	.00024977	75.280
137.90	.00027591	74.761
144.79	.00030442	74.223
151.69	.00033543	73.666
158.58	.00036908	73.094
165.48	.00040552	72.507
172.37	.00044488	71.909
179.26	.00048731	71.299
186.16	.00053295	70.680
193.05	.00058194	70.054
199.95	.00063441	69.421
206.84	.00069052	68.784
213.74	.00075040	68.143
220.63	.00081419	67.500
227.53	.00088204	66.856
234.42	.00095408	66.211

[1] Calculated at 18 percent of ultimate strength.

Table C-1.—*Permanent set, creep, and initial and final modulus values (metric)*—Continued

18 ALUMINUM STRANDS AND 1 STEEL STRAND

Code word	Size, mm²	10-year creep[1]	Tension[1], N	Final modulus, GPa
WAXWING	135.19	.00058691	5508.7	68.031
MERLIN	170.45	.00058702	6949.9	68.031
CHICKADEE	201.41	.00056698	7958.7	68.031
PELICAN	241.70	.00056019	9448.0	68.031
OSPREY	287.05	.00055702	10969.3	68.031
KINGBIRD	322.26	.00055886	12570.6	68.031

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00007997	
13.73	.00011682	49.893
20.68	.00015029	50.516
27.58	.00018134	51.036
34.47	.00021094	51.441
41.37	.00024002	51.725
48.26	.00026954	51.885
55.16	.00030046	51.919
62.05	.00033374	51.831
68.95	.00037032	51.627
75.84	.00041116	51.313
82.74	.00045722	50.900
89.63	.00050944	50.400
96.53	.00056879	49.824
103.42	.00063621	49.183
110.32	.00071266	48.489
117.21	.00079909	47.754
124.11	.00089647	46.985
131.00	.00100573	46.194
137.90	.00112784	45.387
144.79	.00126375	44.570
151.69	.00141442	43.751
158.58	.00158079	42.933
165.48	.00176383	42.120

[1] Calculated at 18 percent of ultimate strength.

Table C-1.—*Permanent set, creep, and initial and final modulus values (metric)*—Continued

24 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, mm²	10-year creep[1]	Tension[1], N	Final modulus, GPa
BRANT	201.41	.00050955	11689.9	72.602
FLICKER	241.70	.00049932	13771.6	72.602
PARAKEET	281.98	.00049191	15853.4	72.602
PEACOCK	306.81	.00049382	17294.6	72.602
ROOK	322.26	.00047682	17614.9	72.602
FLAMINGO	337.46	.00049160	18976.0	72.602
CUCKOO	402.83	.00048458	22338.9	72.602

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00004441	—
13.79	.00007736	53.900
20.68	.00010696	54.625
27.58	.00013378	55.288
34.47	.00015840	55.880
41.37	.00018138	56.395
48.26	.00020330	56.827
55.16	.00022474	57.170
62.05	.00024627	57.422
68.95	.00026846	57.581
75.84	.00029189	57.646
82.74	.00031713	57.620
89.63	.00034475	57.506
96.53	.00037532	57.307
103.42	.00040943	57.029
110.32	.00044764	56.678
117.21	.00049053	56.262
124.11	.00053867	55.787
131.00	.00059263	55.259
137.90	.00065299	54.687
144.79	.00072033	54.077
151.69	.00079521	53.435
158.58	.00087821	52.767
165.48	.00096990	52.079
172.37	.00107086	51.375
179.26	.00118166	50.660
186.16	.00130287	49.939
193.05	.00143507	49.213
199.95	.00157883	48.487

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[1] Calculated at 18 percent of ultimate strength.

Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*–Continued

26 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, mm²	10-year creep[1]	Tension[1] N	Final modulus, GPa
PARTRIDGE	135.19	.00050213	9047.6	74.188
OSTRICH	152.01	.00050168	10168.6	74.188
LINNET	170.45	.00049623	11289.5	74.188
IBIS	201.41	.00048422	13051.0	74.188
HAWK	241.70	.00048255	15613.2	74.188
DOVE	281.98	.00047888	18095.3	74.188
SQUAB	306.55	.00047298	19456.4	74.188
GROSBEAK	322.26	.00046581	20177.0	74.188
STARLING	362.54	.00046675	22739.2	74.188
DRAKE	402.83	.00046583	25221.3	74.188

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00007464	
13.79	.00010656	55.223
20.68	.00013679	55.600
27.58	.00016568	55.932
34.47	.00019357	56.215
41.37	.00022078	56.449
48.26	.00024767	56.631
55.16	.00027456	56.761
62.05	.00030180	56.837
68.95	.00032973	56.860
75.84	.00035868	56.831
82.74	.00038900	56.750
89.63	.00042101	56.619
96.53	.00045507	56.440
103.42	.00049150	56.216
110.32	.00053065	55.948
117.21	.00057285	55.640
124.11	.00061844	55.295
131.00	.00066777	54.915
137.90	.00072116	54.505
144.79	.00077897	54.067
151.69	.00084152	53.604
158.58	.00090915	53.119
165.48	.00098221	52.615
172.37	.00106103	52.096
179.26	.00114595	51.562
186.16	.00123731	51.018
193.05	.00133544	50.465
199.95	.00144069	49.905
206.84	.00155340	49.340

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[1] Calculated at 18 percent of ultimate strength.

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Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*–Continued

30 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, mm²	10-year creep[1]	Tension[1], N	Final modulus, GPa
ORIOLE	170.45	.00041719	13851.7	78.187
LARK	201.41	.00041419	16253.7	78.187
HEN	241.70	.00040398	19056.1	78.187
EAGLE	281.98	.00040442	22258.8	78.187

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00004619	
13.79	.00006826	62.536
20.68	.00008940	62.804
27.58	.00010977	63.040
34.47	.00012958	63.241
41.37	.00014901	63.407
48.26	.00016823	63.538
55.16	.00018745	63.633
62.05	.00020683	63.691
68.95	.00022657	63.713
75.84	.00024684	63.698
82.74	.00026785	63.648
89.63	.00028976	63.563
96.53	.00031276	63.444
103.42	.00033705	63.291
110.32	.00036280	63.106
117.21	.00039020	62.890
124.11	.00041943	62.645
131.00	.00045068	62.372
137.90	.00048413	62.072
144.79	.00051997	61.748
151.69	.00055839	61.401
158.58	.00059956	61.033
165.48	.00064367	60.645
172.37	.00069091	60.240
179.26	.00074147	59.818
186.16	.00079552	59.382
193.05	.00085325	58.933
199.95	.00091485	58.472
206.84	.00098050	58.001
213.74	.00105038	57.522

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[1] Calculated at 18 percent of ultimate strength.

Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*–Continued

45 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, mm²	10-year creep[1]	Tension[1] N	Final modulus, GPa
TERN	402.83	.00057764	17694.9	64.466
RUDDY	456.03	.00056147	19536.5	64.466
RAIL	483.39	.00056215	20737.5	64.466
ORTOLAN	523.67	.00055394	22178.7	64.466
BLUEJAY	563.96	.00055325	23860.1	64.466
BUNTING	604.24	.00055490	25621.6	64.466
BITTERN	644.52	.00055412	27303.1	64.466
DIPPER	684.81	.00055343	28984.5	64.466
BOBOLINK	725.09	.00055282	30665.9	64.466
NUTHATCH	765.37	.00054804	32107.1	64.466
LAPWING	805.65	.00054776	33788.5	64.466

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00007248	
13.79	.00012961	42.020
20.68	.00017972	42.961
27.58	.00022409	43.828
34.47	.00026402	44.606
41.37	.00030081	45.278
48.26	.00033576	45.830
55.16	.00037017	46.251
62.05	.00040532	46.534
68.95	.00044251	46.679
75.84	.00048305	46.686
82.74	.00052822	46.562
89.63	.00057932	46.317
96.53	.00063765	45.963
103.42	.00070450	45.513
110.32	.00078118	44.982
117.21	.00086897	44.384
124.11	.00096917	43.731
131.00	.00108308	43.036
137.90	.00121199	42.309
144.79	.00135721	41.561
151.69	.00152002	40.799
158.58	.00170172	40.030

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[1] Calculated at 18 percent of ultimate strength.

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Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*–Continued

54 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, mm^2	10-year creep[1]	Tension[1], N	Final modulus, GPa
CONDOR	402.83	.00046434	22579.1	67.114
CANARY	456.03	.00046390	25541.6	67.114
CARDINAL	483.39	.00046369	27062.8	67.114
CURLEW	523.67	.00046347	29304.7	67.114

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00005753	
13.79	.00010350	46.368
20.68	.00014543	47.014
27.58	.00018402	47.606
34.47	.00021994	48.136
41.37	.00025388	48.598
48.26	.00028652	48.987
55.16	.00031856	49.297
62.05	.00035066	49.527
68.95	.00038352	49.674
75.84	.00041782	49.738
82.74	.00045425	49.721
89.63	.00049348	49.624
96.53	.00053621	49.453
103.42	.00058311	49.212
110.32	.00063487	48.907
117.21	.00069218	48.543
124.11	.00075571	48.126
131.00	.00082615	47.665
137.90	.00090420	47.163
144.79	.00099052	46.629
151.69	.00108580	46.066
158.58	.00119074	45.482
165.48	.00130600	44.879
172.37	.00143228	44.264
179.26	.00157026	43.639

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[1] Calculated at 18 percent of ultimate strength.

Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*–Continued

54 ALUMINUM STRANDS AND 19 STEEL STRANDS

Code word	Size, mm²	10-year creep[1]	Tension[1], N	Final modulus, GPa
FINCH	563.96	.00050022	31306.4	69.706
GRACKLE	604.24	.00050043	33548.3	69.706
PHEASANT	644.52	.00048771	34909.5	69.706
MARTIN	684.81	.00048760	37071.3	69.706
PLOVER	725.09	.00048851	39313.2	69.706
PARROT	765.37	.00048704	41394.9	69.706
FALCON	805.65	.00048789	43636.8	69.706

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	.00002892	
13.79	.00006013	52.987
20.68	.00008941	53.386
27.58	.00011729	53.717
34.47	.00014431	53.976
41.37	.00017099	54.159
48.26	.00019788	54.267
55.16	.00022551	54.299
62.05	.00025441	54.254
68.95	.00028512	54.136
75.84	.00031817	53.948
82.74	.00035409	53.692
89.63	.00039342	53.374
96.53	.00043669	52.999
103.42	.00048444	52.571
110.32	.00053719	52.097
117.21	.00059549	51.582
124.11	.00065987	51.031
131.00	.00073086	50.451
137.90	.00080900	49.845
144.79	.00089482	49.219
151.69	.00098885	48.577
158.58	.00109163	47.923
165.48	.00120369	47.260
172.37	.00132557	46.592
179.26	.00145779	45.922
186.16	.00160090	45.251

[1] Calculated at 18 percent of ultimate strength.

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Table C-1.–*Permanent set, creep, and initial and final modulus values (metric)*–Continued

84 ALUMINUM STRANDS AND 19 STEEL STRANDS

Code word	Size, mm²	10-year creep[1]	Tension[1], N	Final modulus, GPa
CHUCKAR	901.93	.00071310	40834.5	66.811
BLUEBIRD	1092.45	.00069677	48280.8	66.811
	1552.53	.00069663	68617.9	66.811

Stress, MPa	Permanent set	Initial modulus, GPa
6.89	0.00000000	
13.79	.00003350	50.111
20.68	.00006531	50.590
27.58	.00009538	50.972
34.47	.00012455	51.251
41.37	.00015366	51.423
48.26	.00018356	51.487
55.16	.00021507	51.443
62.05	.00024904	51.296
68.95	.00028631	51.050
75.84	.00032772	50.713
82.74	.00037411	50.293
89.63	.00042632	49.799
96.53	.00048519	49.241
103.42	.00055156	48.628
110.32	.00062627	47.970
117.21	.00071016	47.275
124.11	.00080407	46.551
131.00	.00090885	45.807
137.90	.00102532	45.048
144.79	.00115433	44.280
151.69	.00129672	43.509
158.58	.00145333	42.737
165.48	.00162500	41.970

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[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*

6 ALUMINUM STRANDS AND 1 STEEL STRAND				
Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in²
TURKEY	6	.00046458	214.	11460000.
SWAN	4	.00045465	335.	11460000.
SPARROW	2	.00043810	513.	11460000.
ROBIN	1	.00043228	639.	11460000.
RAVEN	1/0	.00042251	788.	11460000.
QUAIL	2/0	.00040529	956.	11460000.
PIGEON	3/0	.00040014	1192.	11460000.
PENGUIN	4/0	.00040034	1503.	11460000.

Stress, lb/in²	Permanent set	Initial modulus, lb/in²
1000.	.00005034	
2000.	.00006347	9960963.
3000.	.00007589	9996316.
4000.	.00008791	10021891.
5000.	.00009981	10037502.
6000.	.00011190	10043072.
7000.	.00012448	10038633.
8000.	.00013784	10024321.
9000.	.00015228	10000376.
10000.	.00016810	9967127.
11000.	.00018560	9924989.
12000.	.00020507	9874445.
13000.	.00022682	9816035.
14000.	.00025114	9750342.
15000.	.00027834	9677978.
16000.	.00030870	9599568.
17000.	.00034253	9515745.
18000.	.00038012	9427132.
19000.	.00042178	9334340.
20000.	.00046780	9237955.
21000.	.00051848	9138534.
22000.	.00057412	9036604.
23000.	.00063501	8932655.
24000.	.00070146	8827140.
25000.	.00077376	8720474.
26000.	.00085221	8613037.
27000.	.00093712	8505170.
28000.	.00102877	8397179.
29000.	.00112746	8289339.
30000.	.00123350	8181890.

[1] Calculated at 18 percent of ultimate strength.

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Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

7 ALUMINUM STRANDS AND 1 STEEL STRAND

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in²
SWANATE	4	.00048932	425.	12620000.
SPARATE	2	.00047536	655.	12620000.

Stress, lb/in²	Permanent set	Initial modulus, lb/in²
1000.	.00002236	
2000.	.00003009	11497226.
3000.	.00003766	11508882.
4000.	.00004518	11514317.
5000.	.00005282	11513518.
6000.	.00006070	11506512.
7000.	.00006896	11493358.
8000.	.00007776	11474154.
9000.	.00008723	11449026.
10000.	.00009751	11418134.
11000.	.00010874	11381666.
12000.	.00012106	11339833.
13000.	.00013462	11292869.
14000.	.00014955	11241027.
15000.	.00016600	11184574.
16000.	.00018410	11123789.
17000.	.00020401	11058958.
18000.	.00022585	10990372.
19000.	.00024977	10918326.
20000.	.00027591	10843111.
21000.	.00030442	10765016.
22000.	.00033543	10684325.
23000.	.00036908	10601313.
24000.	.00040552	10516247.
25000.	.00044488	10429384.
26000.	.00048731	10340968.
27000.	.00053295	10251233.
28000.	.00058194	10160398.
29000.	.00063441	10068672.
30000.	.00069052	9976248.
31000.	.00075040	9883309.
32000.	.00081419	9790022.
33000.	.00088204	9696544.
34000.	.00095408	9603018.

[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

18 ALUMINUM STRANDS AND 1 STEEL STRAND

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in^2
WAXWING	266.8	.00058691	1238.	9867000.
MERLIN	336.4	.00058702	1562.	9867000.
CHICKADEE	397.5	.00056698	1789.	9867000.
PELICAN	477.0	.00056019	2124.	9867000.
OSPREY	566.5	.00055702	2466.	9867000.
KINGBIRD	636.0	.00055886	2826.	9867000.

Stress, lb/in^2	Permanent set	Initial modulus, lb/in^2
1000.	.00007997	
2000.	.00011682	7236257.
3000.	.00015029	7326749.
4000.	.00018134	7402066.
5000.	.00021094	7460835.
6000.	.00024002	7502070.
7000.	.00026954	7525224.
8000.	.00030046	7530226.
9000.	.00033374	7517466.
10000.	.00037032	7487760.
11000.	.00041116	7442273.
12000.	.00045722	7382441.
13000.	.00050944	7309875.
14000.	.00056879	7226273.
15000.	.00063621	7133343.
16000.	.00071266	7032742.
17000.	.00079909	6926027.
18000.	.00089647	6814624.
19000.	.00100573	6699814.
20000.	.00112784	6582724.
21000.	.00126375	6464328.
22000.	.00141442	6345457.
23000.	.00158079	6226811.
24000.	.00176383	6108966.

[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

24 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in²
BRANT	397.5	.00050955	2628.	10530000.
FLICKER	477.0	.00049932	3096.	10530000.
PARAKEET	556.5	.00049191	3564.	10530000.
PEACOCK	605.5	.00049382	3888.	10530000.
ROOK	636.0	.00047682	3960.	10530000.
FLAMINGO	666.0	.00049160	4266.	10530000.
CUCKOO	795.0	.00048458	5022.	10530000.

Stress, lb/in²	Permanent set	Initial modulus, lb/in²
1000.	.00004441	———
2000.	.00007736	7817435.
3000.	.00010696	7922641.
4000.	.00013378	8018775.
5000.	.00015840	8104704.
6000.	.00018138	8179403.
7000.	.00020330	8241996.
8000.	.00022474	8291796.
9000.	.00024627	8328327.
10000.	.00026846	8351347.
11000.	.00029189	8360853.
12000.	.00031713	8357070.
13000.	.00034475	8340441.
14000.	.00037532	8311590.
15000.	.00040943	8271299.
16000.	.00044764	8220464.
17000.	.00049053	8160059.
18000.	.00053867	8091103.
19000.	.00059263	8014626.
20000.	.00065299	7931642.
21000.	.00072033	7843128.
22000.	.00079521	7750010.
23000.	.00087821	7653147.
24000.	.00096990	7553330.
25000.	.00107086	7451274.
26000.	.00118166	7347619.
27000.	.00130287	7242933.
28000.	.00143507	7137716.
29000.	.00157883	7032400.

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[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

26 ALUMINUM STRANDS AND 7 STEEL STRANDS				
Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in²
PARTRIDGE	266.8	.00050213	2034.	10760000.
OSTRICH	300.0	.00050168	2286.	10760000.
LINNET	336.4	.00049623	2538.	10760000.
IBIS	397.5	.00048422	2934.	10760000.
HAWK	477.0	.00048255	3510.	10760000.
DOVE	556.5	.00047888	4068.	10760000.
SQUAB	605.0	.00047298	4374.	10760000.
GROSBEAK	636.0	.00046581	4536.	10760000.
STARLING	715.5	.00046675	5112.	10760000.
DRAKE	795.0	.00046583	5670.	10760000.

Stress, lb/in²	Permanent set	Initial modulus, lb/in²
1000.	.00007464	
2000.	.00010656	8009304.
3000.	.00013679	8064029.
4000.	.00016568	8112144.
5000.	.00019357	8153295.
6000.	.00022078	8187189.
7000.	.00024767	8213600.
8000.	.00027456	8232378.
9000.	.00030180	8243448.
10000.	.00032973	8246813.
11000.	.00035868	8242554.
12000.	.00038900	8230825.
13000.	.00042101	8211848.
14000.	.00045507	8185905.
15000.	.00049150	8153331.
16000.	.00053065	8114503.
17000.	.00057285	8069834.
18000.	.00061844	8019760.
19000.	.00066777	7964731.
20000.	.00072116	7905206.
21000.	.00077897	7841642.
22000.	.00084152	7774488.
23000.	.00090915	7704182.
24000.	.00098221	7631143.
25000.	.00106103	7555770.
26000.	.00114595	7478440.
27000.	.00123731	7399503.
28000.	.00133544	7319286.
29000.	.00144069	7238088.
30000.	.00155340	7156184.

[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permament set, creep, and initial and final modulus values (U.S. customary)*–Continued

30 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in^2
ORIOLE	336.4	.00041719	3114.	11340000.
LARK	397.5	.00041419	3654.	11340000.
HEN	477.0	.00040398	4284.	11340000.
EAGLE	556.5	.00040442	5004.	11340000.

Stress, lb/in^2	Permanent set	Initial modulus, lb/in^2
1000.	.00004619	
2000.	.00006826	9069999.
3000.	.00008940	9108929.
4000.	.00010977	9143072.
5000.	.00012958	9172274.
6000.	.00014901	9196403.
7000.	.00016823	9215362.
8000.	.00018745	9229082.
9000.	.00020683	9237528.
10000.	.00022657	9240698.
11000.	.00024684	9238620.
12000.	.00026785	9231356.
13000.	.00028976	9218997.
14000.	.00031276	9201662.
15000.	.00033705	9179498.
16000.	.00036280	9152671.
17000.	.00039020	9121373.
18000.	.00041943	9085809.
19000.	.00045068	9046200.
20000.	.00048413	9002779.
21000.	.00051997	8955785.
22000.	.00055839	8905464.
23000.	.00059956	8852064.
24000.	.00064367	8795831.
25000.	.00069091	8737012.
26000.	.00074147	8675847.
27000.	.00079552	8612572.
28000.	.00085325	8547413.
29000.	.00091485	8480591.
30000.	.00098050	8412314.
31000.	.00105038	8342782.

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[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

45 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in^2
TERN	795.0	.00057764	3978.	9350000.
RUCDY	900.0	.00056147	4392.	9350000.
RAIL	954.0	.00056215	4662.	9350000.
ORTOLAN	1,033.5	.00055394	4986.	9350000.
BLUEJAY	1,113.0	.00055325	5364.	9350000.
BUNTING	1,192.5	.00055490	5760.	9350000.
BITTERN	1,272.0	.00055412	6138.	9350000.
DIPPER	1,351.5	.00055343	6516.	9350000.
BOBOLINK	1,431.0	.00055282	6894.	9350000.
NUTHATCH	1,510.5	.00054804	7218.	9350000.
LAPWING	1,590.0	.00054776	7596.	9350000.

Stress, lb/in^2	Permanent set	Initial modulus, lb/in^2
1000.	.00007248	
2000.	.00012961	6094514.
3000.	.00017972	6230875.
4000.	.00022409	6356725.
5000.	.00026402	6469544.
6000.	.00030081	6566978.
7000.	.00033576	6647001.
8000.	.00037017	6708064.
9000.	.00040532	6749205.
10000.	.00044251	6770117.
11000.	.00048305	6771136.
12000.	.00052822	6753185.
13000.	.00057932	6717665.
14000.	.00063765	6666327.
15000.	.00070450	6601128.
16000.	.00078118	6524109.
17000.	.00086897	6437290.
18000.	.00096917	6342586.
19000.	.00108308	6241760.
20000.	.00121199	6136388.
21000.	.00135721	6027851.
22000.	.00152002	5917333.
23000.	.00170172	5805834.

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[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

54 ALUMINUM STRANDS AND 7 STEEL STRANDS

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in²
CONDOR	795.0	.00046434	5076.	9734000.
CANARY	900.0	.00046390	5742.	9734000.
CARDINAL	954.0	.00046369	6084.	9734000.
CURLEW	1.033.5	.00046347	6588.	9734000.

Stress, lb/in²	Permanent set	Initial modulus, lb/in²
1000.	.00005753	
2000.	.00010350	6725040.
3000.	.00014543	6818757.
4000.	.00018402	6904585.
5000.	.00021994	6981488.
6000.	.00025388	7048526.
7000.	.00028652	7104893.
8000.	.00031856	7149946.
9000.	.00035066	7183242.
10000.	.00038352	7204543.
11000.	.00041782	7213835.
12000.	.00045425	7211311.
13000.	.00049348	7197364.
14000.	.00053621	7172554.
15000.	.00058311	7137584.
16000.	.00063487	7093261.
17000.	.00069218	7040465.
18000.	.00075571	6980111.
19000.	.00082615	6913128.
20000.	.00090420	6840425.
21000.	.00099052	6762878.
22000.	.00108580	6681315.
23000.	.00119074	6596501.
24000.	.00130600	6509140.
25000.	.00143228	6419866.
26000.	.00157026	6329243.

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[1] Calculated at 18 percent of ultimate strength.

Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

54 ALUMINUM STRANDS AND 19 STEEL STRANDS

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in^2
FINCH	1,113.0	.00050022	7038.	10110000.
GRACKLE	1,192.5	.00050043	7542.	10110000.
PHEASANT	1,272.0	.00048771	7848.	10110000.
MARTIN	1,351.5	.00048760	8334.	10110000.
PLOVER	1,431.0	.00048851	8838.	10110000.
PARROT	1,510.5	.00048704	9306.	10110000.
FALCON	1,590.0	.00048789	9810.	10110000.

Stress, lb/in^2	Permanent set	Initial modulus, lb/in^2
1000.	.00002892	
2000.	.00006013	7685036.
3000.	.00008941	7742948.
4000.	.00011729	7790922.
5000.	.00014431	7828437.
6000.	.00017099	7855119.
7000.	.00019788	7870755.
8000.	.00022551	7875301.
9000.	.00025441	7868880.
10000.	.00028512	7851773.
11000.	.00031817	7824407.
12000.	.00035409	7787332.
13000.	.00039342	7741200.
14000.	.00043669	7686737.
15000.	.00048444	7624723.
16000.	.00053719	7555962.
17000.	.00059549	7481264.
18000.	.00065987	7401427.
19000.	.00073086	7317221.
20000.	.00080900	7229375.
21000.	.00089482	7138573.
22000.	.00098885	7045445.
23000.	.00109163	6950565.
24000.	.00120369	6854451.
25000.	.00132557	6757566.
26000.	.00145779	6660319.
27000.	.00160090	6563070.

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[1] **Calculated at 18 percent of ultimate strength.**

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Table C-2.–*Permanent set, creep, and initial and final modulus values (U.S. customary)*–Continued

84 ALUMINUM STRANDS AND 19 STEEL STRANDS

Code word	Size, AWG or kcmil	10-year creep[1]	Tension[1], lb	Final modulus, lb/in²
CHUCKAR	1,780.0	.00071310	9180.	9690000.
BLUEBIRD	2,156.0	.00069677	10854.	9690000.
	3,064.0	.00069663	15426.	9690000.

Stress, lb/in²	Permanent set	Initial modulus, lb/in²
1000.	0.00000000	
2000.	.00003350	7267970.
3000.	.00006531	7337414.
4000.	.00009538	7392798.
5000.	.00012455	7433244.
6000.	.00015366	7458197.
7000.	.00018356	7467449.
8000.	.00021507	7461150.
9000.	.00024904	7439784.
10000.	.00028631	7404137.
11000.	.00032772	7355238.
12000.	.00037411	7294302.
13000.	.00042632	7222659.
14000.	.00048519	7141699.
15000.	.00055156	7052811.
16000.	.00062627	6957345.
17000.	.00071016	6856575.
18000.	.00080407	6751677.
19000.	.00090885	6643716.
20000.	.00102532	6533641.
21000.	.00115433	6422281.
22000.	.00129672	6310355.
23000.	.00145333	6198473.
24000.	.00162500	6087152.

[1] Calculated at 18 percent of ultimate strength.

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Table C-3.--*Conductor and overhead ground wire data (metric)*

Code word	Size, mm²	Stranding, aluminum/ steel	Diameter, mm	Area, mm²	Ultimate strength, N	Coeff. of linear expansion, per °C	Force, N/m	0.192-kPa wind, N/m	Resultant, force[1], N/m
TURKEY	13.28	6/ 1	5.03	15.5	5293	.0000189	.5268	.963	1.0979
SWAN	21.13	6/ 1	6.35	24.7	4715	.0000189	.8377	1.216	1.4767
SWANATE	21.13	7/ 1	6.53	26.5	10497	.0000176	.9778	1.250	1.5872
SPARROW	33.64	6/ 1	8.03	39.2	12677	.0000189	1.3324	1.537	2.0343
SPARATE	33.64	7/ 1	8.26	42.1	16191	.0000176	1.5572	1.581	2.2191
ROBIN	42.41	6/ 1	9.02	49.5	15791	.0000189	1.6812	1.727	2.4102
RAVEN	53.46	6/ 1	10.11	62.4	19483	.0000189	2.1190	1.936	2.8703
QUAIL	67.44	6/ 1	11.35	78.6	23619	.0000189	2.6721	2.174	3.4451
PIGEON	85.02	6/ 1	12.75	99.2	29447	.0000189	3.3697	2.442	4.1616
PENGUIN	107.22	6/ 1	14.30	125.1	37142	.0000189	4.2483	2.739	5.0546
GROUSE	40.54	8/ 1	9.32	54.6	23130	.0000153	2.1745	1.785	2.8135
PETREL	51.58	12/ 7	11.71	81.7	46261	.0000153	3.7083	2.243	4.3337
MINORCA	56.14	12/ 7	12.22	88.9	50264	.0000153	4.0367	2.340	4.6658
LEGHORN	68.20	12/ 7	13.46	108.0	60495	.0000153	4.9036	2.578	5.5401
GUINEA	80.57	12/ 7	14.63	127.5	71171	.0000153	5.7909	2.802	6.4332
DOTTEREL	89.64	12/ 7	15.42	141.9	76953	.0000153	6.4417	2.953	7.0863
DORKING	96.68	12/ 7	16.03	153.1	83181	.0000153	6.9511	3.070	7.5987
COCHIN	107.07	12/ 7	16.84	169.5	126328	.0000153	7.6983	3.225	8.3466
OWL	135.19	6/ 7	16.08	152.8	43058	.0000194	4.9970	3.079	5.8696
WAXWING	135.19	18/ 1	15.47	142.6	30603	.0000211	4.2235	2.963	5.1589
PARTRIDGE	135.19	26/ 7	16.31	157.2	50264	.0000189	5.3603	3.123	6.2038
OSTRICH	152.01	26/ 7	17.27	176.8	56492	.0000189	6.0229	3.308	6.8715
MERLIN	170.45	18/ 1	17.37	179.9	38610	.0000211	5.3312	3.327	6.2843
LINNET	170.45	26/ 7	18.31	198.2	62719	.0000189	6.7570	3.507	7.6131
ORIOLE	170.45	30/ 7	18.82	210.3	76953	.0000178	7.6924	3.605	8.4951
CHICKADEE	201.41	18/ 1	18.87	212.6	44215	.0000211	6.2987	3.614	7.2621
BRANT	201.41	24/ 7	19.61	227.5	64943	.0000194	7.4735	3.755	8.3641
IBIS	201.41	26/ 7	19.89	234.2	72505	.0000189	7.9814	3.809	8.8437

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[1] Does not include NESC constant.

Table C-3.–*Conductor and overhead ground wire data (metric)*–Continued

Code word	Size, mm²	Stranding, aluminum/ steel	Diameter, mm	Area, mm²	Ultimate strength, N	Coeff. of linear expansion, per °C	Force, N/m	0.192-kPa wind, N/m	Resultant force[1], N/m
LARK	201.41	30/ 7	20.47	248.4	90298	.0000178	9.0891	3.921	9.8987
PELICAN	241.70	18/ 1	20.68	255.1	52488	.0000211	7.5596	3.960	8.5339
FLICKER	241.70	24/ 7	21.49	273.0	76509	.0000194	8.9680	4.115	9.8672
HAWK	241.70	26/ 7	21.79	281.0	86739	.0000189	9.5882	4.174	10.4573
HEN	241.70	30/ 7	22.43	298.1	105867	.0000178	10.9016	4.295	11.7174
OSPREY	281.98	18/ 1	22.33	297.7	60940	.0000211	8.8147	4.276	9.7971
PARAKEET	281.98	24/ 7	23.22	318.6	88074	.0000194	10.4638	4.446	11.3693
DOVE	281.98	26/ 7	23.55	327.9	100529	.0000189	11.1789	4.510	12.0542
EAGLE	281.98	30/ 7	24.21	347.8	123659	.0000178	12.7259	4.636	13.5440
PEACOCK	306.55	24/ 7	24.21	346.3	96081	.0000194	11.3832	4.636	12.2911
SQUAB	306.55	26/ 7	24.54	356.5	108091	.0000189	12.1567	4.699	13.0334
TEAL	306.55	30/19	25.25	376.5	133446	.0000207	13.7183	4.835	14.5455
KINGBIRD	322.26	18/ 1	23.88	340.1	69836	.0000211	10.0844	4.573	11.0727
ROOK	322.26	24/ 7	24.82	364.1	97860	.0000194	11.9524	4.753	12.8627
GROSBEAK	322.26	26/ 7	25.15	374.8	112094	.0000189	12.7697	4.816	13.6476
EGRET	322.26	30/19	25.88	395.7	140118	.0000207	14.4188	4.957	15.2471
SWIFT	322.26	36/ 1	23.62	331.2	61385	.0000220	9.3941	4.524	10.4267
	331.33	18/ 3	24.21	343.3	65833	.0000218	9.8684	4.636	10.9031
FLAMINGO	337.46	24/ 7	25.40	381.5	105422	.0000194	12.5362	4.865	13.4469
STARLING	362.54	26/ 7	26.70	421.6	126328	.0000189	14.3750	5.113	15.2571
REDWING	362.54	30/19	27.46	445.2	153907	.0000207	16.2138	5.259	17.0453
CUCKOO	402.83	24/ 7	27.74	455.0	124104	.0000194	14.9442	5.312	15.8602
DRAKE	402.83	26/ 7	28.14	468.5	140118	.0000189	15.9657	5.390	16.8510
MALLARD	402.83	30/19	28.96	494.7	170810	.0000207	18.0235	5.546	18.8574
COOT	402.83	36/ 1	26.42	413.9	74729	.0000220	11.7437	5.059	12.7871
TERN	402.83	45/ 7	27.00	430.7	98305	.0000207	13.0761	5.171	14.0615
CONDOR	402.83	54/ 7	27.76	455.0	125439	.0000193	14.9442	5.317	15.8619
RUDDY	456.03	45/ 7	28.73	487.4	108536	.0000207	14.8128	5.502	15.8016

[1] Does not include NESC constant.

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Table C-3.–*Conductor and overhead ground wire data (metric)*–Continued

Code word	Size, mm²	Stranding, aluminum/steel	Diameter, mm	Area, mm²	Ultimate strength, N	Coeff. of linear expansion, per °C	Force, N/m	0.192-kPa wind, N/m	Resultant force[1], N/m
CANARY	456.03	54/ 7	29.51	515.2	141897	.0000193	16.9143	5.653	17.8339
CATBIRD	483.39	36/ 1	28.96	496.9	88074	.0000220	14.0977	5.546	15.1493
RAIL	483.39	45/ 7	29.59	516.8	115208	.0000207	15.6884	5.667	16.6807
CARDINAL	483.39	54/ 7	30.38	546.1	150349	.0000193	17.9359	5.818	18.8560
ORTOLAN	523.67	45/ 7	30.81	559.9	123215	.0000207	17.0019	5.901	17.9968
CURLEW	523.67	54/ 7	31.65	591.5	162804	.0000193	19.4245	6.061	20.3482
BLUEJAY	563.96	45/ 7	31.98	603.0	132556	.0000207	18.3153	6.125	19.3122
FINCH	563.96	54/19	32.84	635.4	173924	.0000194	20.8839	6.290	21.8105
BUNTING	604.24	45/ 7	33.07	645.8	142342	.0000207	19.6142	6.334	20.6115
GRACKLE	604.24	54/19	33.99	680.6	186379	.0000194	22.3724	6.509	23.3000
BITTERN	644.52	45/ 7	34.16	689.0	151683	.0000207	20.9277	6.543	21.9266
PHEASANT	644.52	54/19	35.10	726.5	193941	.0000194	23.8610	6.723	24.7900
DIPPER	684.81	45/ 7	35.20	732.3	161024	.0000207	22.2119	6.742	23.2127
MARTIN	684.81	54/19	36.17	771.6	205951	.0000194	25.3496	6.927	26.2791
BOBOLINK	725.09	45/ 7	36.25	775.5	170366	.0000207	23.5400	6.942	24.5422
PLOVER	725.09	54/19	37.21	816.8	218406	.0000194	26.8528	7.127	27.7824
NUTHATCH	765.37	45/ 7	37.24	818.1	178372	.0000207	24.8388	7.132	25.8423
PARROT	765.37	54/19	38.25	862.6	229971	.0000194	28.3414	7.326	29.2729
LAPWING	805.65	45/ 7	38.15	861.3	187714	.0000207	26.1523	7.307	27.1538
FALCON	805.65	54/19	39.24	907.7	242426	.0000194	29.8299	7.516	30.7622
CHUKAR	901.93	84/19	40.69	975.5	226858	.0000207	30.2677	7.793	31.2549
	1030.63	72/ 7	42.70	1075.4	208175	.0000216	31.5520	8.177	32.5945
BLUEBIRD	1092.45	84/19	44.75	1181.3	268226	.0000207	36.6453	8.571	37.6344
KIWI	1098.02	72/ 7	44.12	1145.8	221520	.0000216	33.6098	8.450	34.6557
	1165.41	96/19	47.17	1313.5	355856	.0000194	43.3147	9.034	44.2467
THRASHER	1171.49	76/19	45.77	1235.1	252212	.0000211	36.8642	8.766	37.8921
JOREE	1274.35	76/19	47.75	1343.6	274453	.0000211	40.1186	9.146	41.1478
	1552.53	84/19	53.37	1679.2	381210	.0000207	52.1002	10.221	53.0933

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[1] Does not include NESC constant.

Table C-3.–*Conductor and overhead ground wire data (metric)*–Continued

Wire type and size	Diameter, mm	Area, mm²	Ultimate strength, N	Coeff. of linear expansion, per °C	Force, N/m	0.192-kPa wind, N/m	Resultant force[1], N/m
STEEL STRAND OVERHEAD GROUND WIRE (7-WIRE)							
9.525 mm HIGH STRENGTH	9.14	51.1	48040	.0000115	3.9841	1.751	4.3520
9.525 mm EXTRA HIGH STRENGTH	9.14	51.1	68502	.0000115	3.9841	1.751	4.3520
11.113 mm HIGH STRENGTH	11.05	74.6	64498	.0000115	5.8230	2.116	6.1956
11.113 mm EXTRA HIGH STRENGTH	11.05	74.6	92522	.0000115	5.8230	2.116	6.1956
12.7 mm HIGH STRENGTH	12.57	96.6	83626	.0000115	7.5450	2.408	7.9200
12.7 mm EXTRA HIGH STRENGTH	12.57	96.6	119656	.0000115	7.5450	2.408	7.9200
ALUMOWELD STRAND OVERHEAD GROUND WIRE							
8M	6.91	29.4	35585	.0000130	1.9118	1.323	2.3250
10M	7.77	36.9	44482	.0000130	2.4080	1.489	2.8310
12.5M	8.71	46.1	55602	.0000130	3.0355	1.669	3.4639
14M	9.22	51.9	62274	.0000130	3.3858	1.766	3.8186
16M	9.80	58.1	71171	.0000130	3.8236	1.878	4.2598
18M	10.59	68.5	80067	.0000130	4.4657	2.029	4.9049
20M	11.28	77.7	88964	.0000130	5.0641	2.160	5.5055
25M	13.18	106.1	111205	.0000130	6.9321	2.525	7.3776
7 NO. 12 AWG	6.15	23.2	28028	.0000130	1.5119	1.177	1.9162
7 NO. 11 AWG	6.91	29.2	35340	.0000130	1.9060	1.323	2.3202
7 NO. 10 AWG	7.77	36.8	44570	.0000130	2.4036	1.489	2.8272
7 NO. 9 AWG	8.71	46.5	56180	.0000130	3.0297	1.669	3.4588
7 NO. 8 AWG	9.78	58.6	70859	.0000130	3.8207	1.873	4.2550
7 NO. 7 AWG	11.00	73.9	84782	.0000130	4.8160	2.106	5.2565
7 NO. 6 AWG	12.34	93.1	101107	.0000130	6.0754	2.364	6.5192
7 NO. 5 AWG	13.87	117.4	120234	.0000130	7.6603	2.656	8.1077

[1] Does not include NESC constant.

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Table C-4.–*Conductor and overhead ground wire data (U.S. customary)*

Code word	Size, AWG or kcmil	Stranding, aluminum/ steel	Diameter, in	Area, in²	Ultimate strength, lb	Coeff. of linear expansion, per °F	Weight, lb/ft	4-lb/ft² wind, lb/ft	Resultant weight,[1] lb/ft
TURKEY	6	6/ 1	.198	.0240	1,190	.0000105	.03610	.06600	.07523
SWAN	4	6/ 1	.250	.0383	1,860	.0000105	.05740	.08333	.10119
SWANATE	4	7/ 1	.257	.0411	2,360	.0000098	.06700	.08567	.10876
SPARROW	2	6/ 1	.316	.0608	2,850	.0000105	.09130	.10533	.13939
SPARATE	2	7/ 1	.325	.0653	3,640	.0000098	.10670	.10833	.15206
ROBIN	1	6/ 1	.355	.0767	3,550	.0000105	.11520	.11833	.16515
RAVEN	1/0	6/ 1	.398	.0967	4,380	.0000105	.14520	.13267	.19668
QUAIL	2/0	6/ 1	.447	.1219	5,310	.0000105	.18310	.14900	.23606
PIGEON	3/0	6/ 1	.502	.1538	6,620	.0000105	.23090	.16733	.28516
PENGUIN	4/0	6/ 1	.563	.1939	8,350	.0000105	.29110	.18767	.34635
GROUSE	80.0	8/ 1	.367	.0847	5,200	.0000085	.14900	.12233	.19279
PETREL	101.8	12/ 7	.461	.1266	10,400	.0000085	.25410	.15367	.29695
MINORCA	110.8	12/ 7	.481	.1378	11,300	.0000085	.27660	.16033	.31971
LEGHORN	134.6	12/ 7	.530	.1674	13,600	.0000085	.33600	.17667	.37961
GUINEA	159.0	12/ 7	.576	.1977	16,000	.0000085	.39680	.19200	.44081
DOTTEREL	176.9	12/ 7	.607	.2200	17,300	.0000085	.44140	.20233	.48556
DORKING	190.8	12/ 7	.631	.2373	18,700	.0000085	.47630	.21033	.52067
COCHIN	211.3	12/ 7	.663	.2628	28,400	.0000085	.52750	.22100	.57192
OWL	266.8	6/ 7	.633	.2368	9,680	.0000108	.34240	.21100	.40219
WAXWING	266.8	18/ 1	.609	.2211	6,880	.0000117	.28940	.20300	.35350
PARTRIDGE	266.8	26/ 7	.642	.2436	11,300	.0000105	.36730	.21400	.42509
OSTRICH	300.0	26/ 7	.680	.2740	12,700	.0000105	.41270	.22667	.47085
MERLIN	336.4	18/ 1	.684	.2789	8,680	.0000117	.36530	.22800	.43061
LINNET	336.4	26/ 7	.721	.3072	14,100	.0000105	.46300	.24033	.52166
ORIOLE	336.4	30/ 7	.741	.3259	17,300	.0000099	.52710	.24700	.58210
CHICKADEE	397.5	18/ 1	.743	.3295	9,940	.0000117	.43160	.24767	.49761
BRANT	397.5	24/ 7	.772	.3527	14,600	.0000108	.51210	.25733	.57312
IBIS	397.5	26/ 7	.783	.3630	16,300	.0000105	.54690	.26100	.60599

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[1] Does not include NESC constant.

Table C-4.–*Conductor and overhead ground wire data (U.S. customary)*–Continued

Code word	Size, AWG or kcmil	Stranding, aluminum/ steel	Diameter, in	Area, in²	Ultimate strength, lb	Coeff. of linear expansion, per °F	Weight, lb/ft	4-lb/ft² wind, lb/ft	Resultant weight,[1] lb/ft
LARK	397.5	30/ 7	.806	.3850	20,300	.0000099	.62280	.26867	.67828
PELICAN	477.0	18/ 1	.814	.3954	11,800	.0000117	.51800	.27133	.58476
FLICKER	477.0	24/ 7	.846	.4232	17,200	.0000108	.61450	.28200	.67612
HAWK	477.0	26/ 7	.858	.4356	19,500	.0000105	.65700	.28600	.71655
HEN	477.0	30/ 7	.883	.4620	23,800	.0000099	.74700	.29433	.80290
OSPREY	556.5	18/ 1	.879	.4614	13,700	.0000117	.60400	.29300	.67132
PARAKEET	556.5	24/ 7	.914	.4938	19,800	.0000108	.71700	.30467	.77904
DOVE	556.5	26/ 7	.927	.5083	22,600	.0000105	.76600	.30900	.82598
EAGLE	556.5	30/ 7	.953	.5391	27,800	.0000099	.87200	.31767	.92806
PEACOCK	605.0	24/ 7	.953	.5368	21,600	.0000108	.78000	.31767	.84221
SQUAB	605.0	26/ 7	.966	.5526	24,300	.0000105	.83300	.32200	.89307
TEAL	605.0	30/19	.994	.5835	30,000	.0000115	.94000	.33133	.99669
KINGBIRD	636.0	18/ 1	.940	.5272	15,700	.0000117	.69100	.31333	.75872
ROOK	636.0	24/ 7	.977	.5643	22,000	.0000108	.81900	.32567	.88137
GROSBEAK	636.0	26/ 7	.990	.5809	25,200	.0000105	.87500	.33000	.93516
EGRET	636.0	30/19	1.019	.6134	31,500	.0000115	.98800	.33967	1.04476
SWIFT	636.0	36/ 1	.930	.5133	13,800	.0000122	.64370	.31000	.71446
	653.9	18/ 3	.953	.5321	14,800	.0000121	.67620	.31767	.74710
FLAMINGO	666.0	24/ 7	1.000	.5914	23,700	.0000108	.85900	.33333	.92141
STARLING	715.5	26/ 7	1.051	.6535	28,400	.0000105	.98500	.35033	1.04545
REDWING	715.5	30/19	1.081	.6901	34,600	.0000115	1.11100	.36033	1.16797
CUCKOO	795.0	24/ 7	1.092	.7053	27,900	.0000108	1.02400	.36400	1.08677
DRAKE	795.0	26/ 7	1.108	.7261	31,500	.0000105	1.09400	.36933	1.15466
MALLARD	795.0	30/19	1.140	.7668	38,400	.0000115	1.23500	.38000	1.29214
COOT	795.0	36/ 1	1.040	.6416	16,800	.0000122	.80470	.34667	.87620
TERN	795.0	45/ 7	1.063	.6676	22,100	.0000115	.89600	.35433	.96352
CONDOR	795.0	54/ 7	1.093	.7053	28,200	.0000107	1.02400	.36433	1.08688
RUDDY	900.0	45/ 7	1.131	.7555	24,400	.0000115	1.01500	.37700	1.08275

[1] Does not include NESC constant.

Table C-4.–*Conductor and overhead ground wire data (U.S. customary)*–Continued

Code word	Size, AWG or kcmil	Stranding, aluminum/ steel	Diameter, in	Area, in²	Ultimate strength, lb	Coeff. of linear expansion, per °F	Weight, lb/ft	4-lb/ft² wind, lb/ft	Resultant weight,[1] lb/ft
CANARY	900.0	54/ 7	1.162	.7985	31,900	.0000107	1.15900	.38733	1.22201
CATBIRD	954.0	36/ 1	1.140	.7702	19,800	.0000122	.96600	.38000	1.03805
RAIL	954.0	45/ 7	1.165	.8011	25,900	.0000115	1.07500	.38833	1.14299
CARDINAL	954.0	54/ 7	1.196	.8464	33,800	.0000107	1.22900	.39867	1.29204
ORTOLAN	1,033.5	45/ 7	1.213	.8678	27,700	.0000115	1.16500	.40433	1.23317
CURLEW	1,033.5	54/ 7	1.246	.9169	36,600	.0000107	1.33100	.41533	1.39430
BLUEJAY	1,113.0	45/ 7	1.259	.9346	29,800	.0000115	1.25500	.41967	1.32331
FINCH	1,113.0	54/19	1.293	.9849	39,100	.0000108	1.43100	.43100	1.49450
BUNTING	1,192.5	45/ 7	1.302	1.0010	32,000	.0000115	1.34400	.43400	1.41234
GRACKLE	1,192.5	54/19	1.338	1.0550	41,900	.0000108	1.53300	.44600	1.59656
BITTERN	1,272.0	45/ 7	1.345	1.0680	34,100	.0000115	1.43400	.44833	1.50245
PHEASANT	1,272.0	54/19	1.382	1.1260	43,600	.0000108	1.63500	.46067	1.69866
DIPPER	1,351.5	45/ 7	1.386	1.1350	36,200	.0000115	1.52200	.46200	1.59057
MARTIN	1,351.5	54/19	1.424	1.1960	46,300	.0000108	1.73700	.47467	1.80069
BOBOLINK	1,431.0	45/ 7	1.427	1.2020	38,300	.0000115	1.61300	.47567	1.68167
PLOVER	1,431.0	54/19	1.465	1.2660	49,100	.0000108	1.84000	.48833	1.90370
NUTHATCH	1,510.5	45/ 7	1.466	1.2680	40,100	.0000115	1.70200	.48867	1.77076
PARROT	1,510.5	54/19	1.506	1.3370	51,700	.0000108	1.94200	.50200	2.00583
LAPWING	1,590.0	45/ 7	1.502	1.3350	42,200	.0000115	1.79200	.50067	1.86063
FALCON	1,590.0	54/19	1.545	1.4070	54,500	.0000108	2.04400	.51500	2.10788
CHUKAR	1,780.0	84/19	1.602	1.5120	51,000	.0000115	2.07400	.53400	2.14164
	2,034.0	72/ 7	1.681	1.6669	46,800	.0000120	2.16200	.56033	2.23343
BLUEBIRD	2,156.0	84/19	1.762	1.8310	60,300	.0000115	2.51100	.58733	2.57878
KIWI	2,167.0	72/ 7	1.737	1.7760	49,800	.0000120	2.30300	.57900	2.37467
	2,300.0	96/19	1.857	2.0359	80,000	.0000108	2.96800	.61900	3.03186
THRASHER	2,312.0	76/19	1.802	1.9144	56,700	.0000117	2.52600	.60067	2.59644
JOREE	2,515.0	76/19	1.880	2.0826	61,700	.0000117	2.74900	.62667	2.81952
	3,064.0	84/19	2.101	2.6028	85,700	.0000115	3.57000	.70033	3.63804

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[1] Does not include NESC constant.

Table C-4.–*Conductor and overhead ground wire data (U.S. customary)*–Continued

Wire type and size	Diameter, in	Area, in²	Ultimate strength, lb	Coeff. of linear expansion, per °F	Weight, lb/ft	4-lb/ft² wind, lb/ft	Resultant weight,[1] lb/ft
STEEL STRAND OVERHEAD GROUND WIRE (7-WIRE)							
3/8 INCH HIGH STRENGTH	.360	.0792	10,800	.0000064	.27300	.12000	.29821
3/8 INCH EXTRA HIGH STRENGTH	.360	.0792	15,400	.0000064	.27300	.12000	.29821
7/16 INCH HIGH STRENGTH	.435	.1156	14,500	.0000064	.39900	.14500	.42453
7/16 INCH EXTRA HIGH STRENGTH	.435	.1156	20,800	.0000064	.39900	.14500	.42453
1/2 INCH HIGH STRENGTH	.495	.1497	18,800	.0000064	.51700	.16500	.54269
1/2 INCH EXTRA HIGH STRENGTH	.495	.1497	26,900	.0000064	.51700	.16500	.54269
ALUMOWELD STRAND OVERHEAD GROUND WIRE							
8M	.272	.0455	8,000	.0000072	.13100	.09067	.15932
10M	.306	.0572	10,000	.0000072	.16500	.10200	.19398
12.5M	.343	.0714	12,500	.0000072	.20800	.11433	.23735
14M	.363	.0805	14,000	.0000072	.23200	.12100	.26166
16M	.386	.0901	16,000	.0000072	.26200	.12867	.29189
18M	.417	.1062	18,000	.0000072	.30600	.13900	.33609
20M	.444	.1204	20,000	.0000072	.34700	.14800	.37724
25M	.519	.1645	25,000	.0000072	.47500	.17300	.50552
7 NO. 12 AWG	.242	.0359	6,301	.0000072	.10360	.08067	.13130
7 NO. 11 AWG	.272	.0453	7,945	.0000072	.13060	.09067	.15899
7 NO. 10 AWG	.306	.0571	10,020	.0000072	.16470	.10200	.19373
7 NO. 9 AWG	.343	.0720	12,630	.0000072	.20760	.11433	.23700
7 NO. 8 AWG	.385	.0908	15,930	.0000072	.26180	.12833	.29156
7 NO. 7 AWG	.433	.1145	19,060	.0000072	.33000	.14433	.36018
7 NO. 6 AWG	.486	.1443	22,730	.0000072	.41630	.16200	.44671
7 NO. 5 AWG	.546	.1820	27,030	.0000072	.52490	.18200	.55556

[1] Does not include NESC constant.

Table C-5.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (metric)*

Code word	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Force with no ice	0.431-kPa wind	Resultant force[1]	Force with 6.35-mm ice	0.192-kPa wind	Resultant force[2]	Force with 12.7-mm ice	0.192-kPa wind	Resultant force[3]
TURKEY	.5268	2.1672	2.9600	2.5602	3.3955	7.1713	6.8629	5.8278	13.3816
SWAN	.8377	2.7364	3.5914	3.1070	3.6485	7.7110	7.6457	6.0808	14.1472
SWANATE	.9778	2.8130	3.7078	3.2789	3.6825	7.8495	7.8494	6.1148	14.3283
SPARROW	1.3324	3.4588	4.4362	3.9013	3.9695	8.4845	8.7396	6.4019	15.2116
SPARATE	1.5572	3.5573	4.6129	4.1669	4.0133	8.7041	9.0460	6.4456	15.4857
ROBIN	1.6812	3.8856	4.9634	4.4271	4.1593	8.9932	9.4424	6.5916	15.8937
RAVEN	2.1190	4.3563	5.5740	5.0601	4.3684	9.6037	10.2705	6.8008	16.6962
QUAIL	2.6721	4.8926	6.3045	5.8356	4.6068	10.3536	11.2684	7.0391	17.6645
PIGEON	3.3697	5.4946	7.1753	6.7828	4.8744	11.2714	12.4653	7.3067	18.8271
PENGUIN	4.2483	6.1623	8.2144	7.9382	5.1711	12.3928	13.8976	7.6034	20.2197
GROUSE	2.1745	4.0170	5.2975	4.9749	4.2176	9.4409	10.0446	6.6500	16.4246
PETREL	3.7083	5.0458	6.9916	6.9353	4.6749	11.2826	12.4317	7.1072	18.6981
MINORCA	4.0367	5.2647	7.3639	7.3545	4.7722	11.6859	12.9416	7.2045	19.1900
LEGHORN	4.9036	5.8011	8.3256	8.4437	5.0106	12.7373	14.2533	7.4429	20.4577
GUINEA	5.7909	6.3046	9.2902	9.5398	5.2343	13.8003	15.5581	7.6667	21.7227
DOTTEREL	6.4417	6.6439	9.9837	10.3314	5.3851	14.5694	16.4904	7.8175	22.6278
DORKING	6.9511	6.9066	10.5286	10.9497	5.5019	15.1730	17.2176	7.9342	23.3360
COCHIN	7.6983	7.2568	11.3092	11.8421	5.6576	16.0430	18.2553	8.0899	24.3457
OWL	4.9970	6.9285	9.2721	9.0046	5.5116	13.4763	15.2817	7.9439	21.6013
WAXWING	4.2235	6.6658	8.6208	8.1222	5.3949	12.6694	14.2903	7.8272	20.6717
PARTRIDGE	5.3603	7.0270	9.5678	9.4089	5.5554	13.8453	15.7267	7.9877	22.0172
OSTRICH	6.0229	7.4429	10.3042	10.2439	5.7403	14.6614	16.7342	8.1726	23.0014
MERLIN	5.3312	7.4867	9.9205	9.5703	5.7597	14.0886	16.0788	8.1920	22.4236
LINNET	6.7570	7.8917	11.1189	11.1641	5.9397	15.5646	17.8405	8.3720	24.0854
ORIOLE	7.6924	8.1106	11.9080	12.1903	6.0370	16.5220	18.9575	8.4693	25.1415
CHICKADEE	6.2987	8.1325	11.0161	10.8057	6.0467	15.3012	17.5819	8.4791	23.8979
BRANT	7.4735	8.4499	12.0104	12.1121	6.1878	16.5199	19.0200	8.6201	25.2604
IBIS	7.9814	8.5703	12.4409	12.6699	6.2413	17.0425	19.6277	8.6736	25.8370

ALL VALUES ARE IN NEWTONS PER METER.

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[1] Includes 0.7297 NESC constant.
[2] Includes 2.9188 NESC constant.
[3] Includes 4.3782 NESC constant.

Table C-5.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (metric)*–Continued

Code word	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Force with no ice	0.431-kPa wind	Resultant force[1]	Force with 6.35-mm ice	0.192-kPa wind	Resultant force[2]	Force with 12.7-mm ice	0.192-kPa wind	Resultant force[3]
LARK	9.0891	8.8220	13.3962	13.8820	6.3532	18.1855	20.9442	8.7855	27.0904
PELICAN	7.5596	8.9096	12.4142	12.3888	6.3921	16.8594	19.4874	8.8244	25.7704
FLICKER	8.9680	9.2598	13.6203	13.9424	6.5478	18.3221	21.1861	8.9801	27.3889
HAWK	9.5882	9.3912	14.1509	14.6171	6.6062	18.9594	21.9153	9.0385	28.0842
HEN	10.9016	9.6648	15.2986	16.0440	6.7278	20.3163	23.4557	9.1601	29.5591
OSPREY	8.8147	9.6210	13.7782	13.9389	6.7083	18.3879	21.3325	9.1406	27.5865
PARAKEET	10.4638	10.0041	15.2064	15.7469	6.8786	20.1025	23.2993	9.3109	29.4690
DOVE	11.1789	10.1464	15.8266	16.5210	6.9418	20.8389	24.1324	9.3741	30.2673
EAGLE	12.7259	10.4310	17.1843	18.1859	7.0683	22.4300	25.9154	9.5006	31.9801
PEACOCK	11.3832	10.4310	16.1694	16.8433	7.0683	21.1851	24.5727	9.5006	30.7236
SQUAB	12.1567	10.5733	16.8412	17.6758	7.1316	21.9790	25.4642	9.5639	31.5791
TEAL	13.7183	10.8798	18.2385	19.3644	7.2678	23.6021	27.2799	9.7001	33.3313
KINGBIRD	10.0844	10.2887	15.1364	15.4854	7.0051	19.9150	23.1558	9.4374	29.3833
ROOK	11.9524	10.6937	16.7676	17.5214	7.1851	21.8562	25.3597	9.6174	31.5003
GROSBEAK	12.7697	10.8360	17.4773	18.3977	7.2483	22.6928	26.2950	9.6806	32.3985
EGRET	14.4188	11.1534	18.9588	20.1784	7.3894	24.4076	28.2074	9.8217	34.2466
SWIFT	9.3941	10.1792	14.5813	14.7498	6.9564	19.2267	22.3748	9.3887	28.6429
	9.8684	10.4310	15.0890	15.3285	7.0683	19.7984	23.0579	9.5006	29.3166
FLAMINGO	12.5362	10.9454	17.3717	18.2095	7.2970	22.5359	26.1523	9.7293	32.2816
STARLING	14.3750	11.5036	19.1409	20.2798	7.5450	24.5567	28.4540	9.9774	34.5308
REDWING	16.2138	11.8320	20.8017	22.2548	7.6910	26.4651	30.5652	10.1233	36.5762
CUCKOO	14.9442	11.9524	19.8657	21.0351	7.7445	25.3342	29.3954	10.1768	35.4853
DRAKE	15.9657	12.1275	20.7792	22.1293	7.8223	26.3899	30.5622	10.2546	36.6149
MALLARD	18.0235	12.4778	22.6509	24.3323	7.9780	28.5256	32.9104	10.4103	38.8958
COOT	11.7437	11.3832	17.0849	17.5986	7.4915	22.0456	25.7229	9.9239	31.9490
TERN	13.0761	11.6350	18.2328	19.0355	7.6034	23.4166	27.2641	10.0357	33.4307
CONDOR	14.9442	11.9633	19.8726	21.0396	7.7494	25.3402	29.4045	10.1817	35.4955
RUDDY	14.8128	12.3793	20.0342	21.0808	7.9342	25.4432	29.6181	10.3665	35.7580

ALL VALUES ARE IN NEWTONS PER METER.

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[1] Includes 0.7297 NESC constant.

[2] Includes 2.9188 NESC constant.

[3] Includes 4.3782 NESC constant.

Table C-5.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (metric)*–Continued

Code word	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Force with no ice	0.431-kPa wind	Resultant force[1]	Force with 6.35-mm ice	0.192-kPa wind	Resultant force[2]	Force with 12.7-mm ice	0.192-kPa wind	Resultant force[3]
CANARY	16.9143	12.7186	21.8923	23.3230	8.0850	27.6034	32.0010	10.5173	38.0631
CATBIRD	14.0977	12.4778	19.5563	20.4065	7.9780	24.8294	28.9847	10.4103	35.1756
RAIL	15.6884	12.7514	20.9467	22.1107	8.0996	26.4663	30.8023	10.5319	36.9313
CARDINAL	17.9359	13.0907	22.9347	24.4989	8.2504	28.7696	33.3312	10.6827	39.3794
ORTOLAN	17.0019	13.2768	22.3014	23.6420	8.3331	27.9864	32.5515	10.7654	38.6636
CURLEW	19.4245	13.6380	24.4638	26.2144	8.4936	30.4748	35.2736	10.9260	41.3052
BLUEJAY	18.3153	13.7803	23.6502	25.1642	8.5569	29.4981	34.2825	10.9892	40.3789
FINCH	20.8839	14.1524	25.9572	27.8871	8.7223	32.1381	37.1597	11.1546	43.1759
BUNTING	19.6142	14.2509	24.9744	26.6583	8.7661	30.9813	35.9717	11.1984	42.0526
GRACKLE	22.3724	14.6450	27.4692	29.5799	8.9412	33.8205	39.0567	11.3735	45.0572
BITTERN	20.9277	14.7216	26.3166	28.1669	8.9752	32.4811	37.6755	11.4076	43.7428
PHEASANT	23.8610	15.1266	28.9815	31.2682	9.1552	35.4997	40.9447	11.5876	46.9310
DIPPER	22.2119	15.1704	27.6278	29.6372	9.1747	33.9436	39.3319	11.6070	45.3870
MARTIN	25.3496	15.5863	30.4876	32.9474	9.3596	37.1698	42.8145	11.7919	48.7869
BOBOLINK	23.5400	15.6191	28.9801	31.1514	9.3741	35.4500	41.0321	11.8065	47.0751
PLOVER	26.8528	16.0350	32.0058	34.6367	9.5590	38.8503	44.6899	11.9913	50.6489
NUTHATCH	24.8388	16.0460	30.3006	32.6272	9.5639	36.9188	42.6850	11.9962	48.7168
PARROT	28.3414	16.4838	33.5161	36.3113	9.7585	40.5185	46.5506	12.1908	52.4986
LAPWING	26.1523	16.4400	31.6201	34.1041	9.7390	38.3862	44.3252	12.1713	50.3441
FALCON	29.8299	16.9107	35.0196	37.9769	9.9482	42.1770	48.3932	12.3805	54.3300
CHUKAR	30.2677	17.5346	35.7097	38.6734	10.2255	42.9212	49.3485	12.6578	55.3241
	31.5520	18.3993	37.2545	40.3162	10.6098	44.6077	51.3498	13.0421	57.3584
BLUEBIRD	36.6453	19.2858	42.1401	45.7772	11.0038	49.9999	57.1784	13.4361	63.1140
KIWI	33.6098	19.0122	39.3442	42.6282	10.8822	46.9140	53.9159	13.3145	59.9138
	43.3147	20.3257	48.5763	52.8777	11.4659	57.0254	64.7101	13.8983	70.5640
THRASHER	36.8642	19.7237	42.5387	46.1776	11.1984	50.4348	57.7604	13.6307	63.7251
JOREE	40.1186	20.5774	45.8178	49.7861	11.5778	54.0333	61.7229	14.0101	67.6711
	52.1002	22.9963	57.6794	62.7707	12.6529	66.9520	75.7106	15.0852	81.5770

ALL VALUES ARE IN NEWTONS PER METER.

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[1] Includes 0.7297 NESC constant.
[2] Includes 2.9188 NESC constant.
[3] Includes 4.3782 NESC constant.

Table C-5.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (metric)*–Continued

Wire type and size	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Force with no ice	0.431-kPa wind	Resultant force[1]	Force with 6.35-mm ice	0.192-kPa wind	Resultant force[2]	Force with 12.7-mm ice	0.192-kPa wind	Resultant force[3]
STEEL STRAND OVERHEAD GROUND WIRE (7-WIRE)									
9.525 mm HS	3.9841	3.9404	6.3332	6.7527	4.1836	10.8625	11.7907	6.6159	17.8982
9.525 mm EHS	3.9841	3.9404	6.3332	6.7527	4.1836	10.8625	11.7907	6.6159	17.8982
11.11 mm HS	5.8230	4.7613	8.2514	8.9320	4.5484	12.9422	14.3103	6.9807	20.3004
11.11 mm EHS	5.8230	4.7613	8.2514	8.9320	4.5484	12.9422	14.3103	6.9807	20.3004
12.7 mm HS	7.5450	5.4180	10.0185	10.9264	4.8403	14.8693	16.5771	7.2726	22.4804
12.7 mm EHS	7.5450	5.4180	10.0185	10.9264	4.8403	14.8693	16.5771	7.2726	22.4804
ALUMOWELD STRAND OVERHEAD GROUND WIRE									
8M	1.9118	2.9772	4.2678	4.2810	3.7555	8.6136	8.9196	6.1878	15.2339
10M	2.4080	3.3493	4.8548	4.9315	3.9209	9.2190	9.7244	6.3532	15.9940
12.5M	3.0355	3.7543	5.5576	5.7270	4.1009	9.9626	10.6878	6.5332	16.9046
14M	3.3858	3.9732	5.9498	6.1680	4.1982	10.3799	11.2196	6.6305	17.4105
16M	3.8236	4.2249	6.4279	6.7102	4.3101	10.8940	11.8662	6.7424	18.0261
18M	4.4657	4.5642	7.1152	7.4930	4.4609	11.6392	12.7897	6.8932	18.9072
20M	5.0641	4.8598	7.7484	8.2139	4.5922	12.3293	13.6332	7.0245	19.7146
25M	6.9321	5.6807	9.6921	10.4224	4.9571	14.4599	16.1820	7.3894	22.1675
7 NO. 12	1.5119	2.6488	3.7796	3.7450	3.6096	8.1201	8.2474	6.0419	14.6018
7 NO. 11	1.9060	2.9772	4.2647	4.2752	3.7555	8.6092	8.9137	6.1878	15.2291
7 NO. 10	2.4036	3.3493	4.8522	4.9271	3.9209	9.2156	9.7200	6.3532	15.9903
7 NO. 9	3.0297	3.7543	5.5540	5.7211	4.1009	9.9579	10.6819	6.5332	16.8996
7 NO. 8	3.8207	4.2140	6.4179	6.7028	4.3052	10.8851	11.8542	6.7375	18.0133
7 NO. 7	4.8160	4.7394	7.4866	7.9159	4.5387	12.0436	13.2852	6.9710	19.3812
7 NO. 6	6.0754	5.3195	8.8048	9.4159	4.7965	13.4860	15.0258	7.2288	21.0524
7 NO. 5	7.6603	5.9762	10.4454	11.2731	5.0884	15.2871	17.1553	7.5207	23.1096

ALL VALUES ARE IN NEWTONS PER METER.

[1] Includes 0.7297 NESC constant.
[2] Includes 2.9188 NESC constant.
[3] Includes 4.3782 NESC constant.

Table C-6.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (U.S. customary)*

Code word	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Weight with no ice	9-lb/ft^2 wind	Resultant weight[1]	Weight with 1/4-in ice	4-lb/ft^2 wind	Resultant weight[2]	Weight with 1/2-in ice	4-lb/ft^2 wind	Resultant weight[3]
TURKEY	.0361	.1485	.2028	.1754	.2327	.4914	.4703	.3993	.9169
SWAN	.0574	.1875	.2461	.2129	.2500	.5284	.5239	.4167	.9694
SWANATE	.0670	.1928	.2541	.2247	.2523	.5379	.5379	.4190	.9818
SPARROW	.0913	.2370	.3040	.2673	.2720	.5814	.5989	.4387	1.0423
SPARATE	.1067	.2438	.3161	.2855	.2750	.5964	.6199	.4417	1.0611
ROBIN	.1152	.2663	.3401	.3034	.2850	.6162	.6470	.4517	1.0891
RAVEN	.1452	.2985	.3819	.3467	.2993	.6581	.7038	.4660	1.1441
QUAIL	.1831	.3353	.4320	.3999	.3157	.7094	.7721	.4823	1.2104
PIGEON	.2309	.3765	.4917	.4648	.3340	.7723	.8541	.5007	1.2901
PENGUIN	.2911	.4223	.5629	.5439	.3543	.8492	.9523	.5210	1.3855
GROUSE	.1490	.2753	.3630	.3409	.2890	.6469	.6883	.4557	1.1254
PETREL	.2541	.3458	.4791	.4752	.3203	.7731	.8518	.4870	1.2812
MINORCA	.2766	.3608	.5046	.5039	.3270	.8007	.8868	.4937	1.3149
LEGHORN	.3360	.3975	.5705	.5786	.3433	.8728	.9767	.5100	1.4018
GUINEA	.3968	.4320	.6366	.6537	.3587	.9456	1.0661	.5253	1.4885
DOTTEREL	.4414	.4553	.6841	.7079	.3690	.9983	1.1300	.5357	1.5505
DORKING	.4763	.4733	.7214	.7503	.3770	1.0397	1.1798	.5437	1.5990
COCHIN	.5275	.4973	.7749	.8114	.3877	1.0993	1.2509	.5543	1.6682
OWL	.3424	.4748	.6353	.6170	.3777	.9234	1.0471	.5443	1.4802
WAXWING	.2894	.4568	.5907	.5565	.3697	.8681	.9792	.5363	1.4165
PARTRIDGE	.3673	.4815	.6556	.6447	.3807	.9487	1.0776	.5473	1.5087
OSTRICH	.4127	.5100	.7061	.7019	.3933	1.0046	1.1467	.5600	1.5761
MERLIN	.3653	.5130	.6798	.6558	.3947	.9654	1.1017	.5613	1.5365
LINNET	.4630	.5408	.7619	.7650	.4070	1.0665	1.2225	.5737	1.6504
ORIOLE	.5271	.5558	.8160	.8353	.4137	1.1321	1.2990	.5803	1.7227
CHICKADEE	.4316	.5573	.7548	.7404	.4143	1.0485	1.2047	.5810	1.6375
BRANT	.5121	.5790	.8230	.8299	.4240	1.1320	1.3033	.5907	1.7309
IBIS	.5469	.5873	.8525	.8682	.4277	1.1678	1.3449	.5943	1.7704

ALL VALUES ARE IN POUNDS PER FOOT.

[1] Includes 0.05 NESC constant.
[2] Includes 0.20 NESC constant.
[3] Includes 0.30 NESC constant.

Table C-6.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (U.S. customary)*–Continued

Code word	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Weight with no ice	9-lb/ft² wind	Resultant weight[1]	Weight with 1/4-in ice	4-lb/ft² wind	Resultant weight[2]	Weight with 1/2-in ice	4-lb/ft² wind	Resultant weight[3]
LARK	.6228	.6045	.9179	.9512	.4353	1.2461	1.4351	.6020	1.8563
PELICAN	.5180	.6105	.8506	.8489	.4380	1.1552	1.3353	.6047	1.7658
FLICKER	.6145	.6345	.9333	.9554	.4487	1.2555	1.4517	.6153	1.8767
HAWK	.6570	.6435	.9696	1.0016	.4527	1.2991	1.5017	.6193	1.9244
HEN	.7470	.6623	1.0483	1.0994	.4610	1.3921	1.6072	.6277	2.0254
OSPREY	.6040	.6593	.9441	.9551	.4597	1.2600	1.4617	.6263	1.8903
PARAKEET	.7170	.6855	1.0420	1.0790	.4713	1.3775	1.5965	.6380	2.0193
DOVE	.7660	.6953	1.0845	1.1320	.4757	1.4279	1.6536	.6423	2.0740
EAGLE	.8720	.7148	1.1775	1.2461	.4843	1.5369	1.7758	.6510	2.1913
PEACOCK	.7800	.7148	1.1080	1.1541	.4843	1.4516	1.6838	.6510	2.1052
SQUAB	.8330	.7245	1.1540	1.2112	.4887	1.5060	1.7449	.6553	2.1639
TEAL	.9400	.7455	1.2497	1.3269	.4980	1.6173	1.8693	.6647	2.2839
KINGBIRD	.6910	.7050	1.0372	1.0611	.4800	1.3646	1.5867	.6467	2.0134
ROOK	.8190	.7328	1.1489	1.2006	.4923	1.4976	1.7377	.6590	2.1585
GROSBEAK	.8750	.7425	1.1976	1.2606	.4967	1.5550	1.8018	.6633	2.2200
EGRET	.9880	.7643	1.2991	1.3827	.5063	1.6725	1.9328	.6730	2.3466
SWIFT	.6437	.6975	.9991	1.0107	.4767	1.3174	1.5332	.6433	1.9627
	.6762	.7148	1.0339	1.0503	.4843	1.3566	1.5800	.6510	2.0088
FLAMINGO	.8590	.7500	1.1903	1.2478	.5000	1.5442	1.7920	.6667	2.2120
STARLING	.9850	.7883	1.3116	1.3896	.5170	1.6827	1.9497	.6837	2.3661
REDWING	1.1110	.8108	1.4254	1.5249	.5270	1.8134	2.0944	.6937	2.5063
CUCKOO	1.0240	.8190	1.3612	1.4414	.5307	1.7359	2.0142	.6973	2.4315
DRAKE	1.0940	.8310	1.4238	1.5163	.5360	1.8083	2.0942	.7027	2.5089
MALLARD	1.2350	.8550	1.5521	1.6673	.5467	1.9546	2.2551	.7133	2.6652
COOT	.8047	.7800	1.1707	1.2059	.5133	1.5106	1.7626	.6800	2.1892
TERN	.8960	.7973	1.2493	1.3043	.5210	1.6045	1.8682	.6877	2.2907
CONDOR	1.0240	.8198	1.3617	1.4417	.5310	1.7364	2.0148	.6977	2.4322
RUDDY	1.0150	.8483	1.3728	1.4445	.5437	1.7434	2.0295	.7103	2.4502

ALL VALUES ARE IN POUNDS PER FOOT.

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[1] Includes 0.05 NESC constant.
[2] Includes 0.20 NESC constant.
[3] Includes 0.30 NESC constant.

Table C-6.–*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (U.S. customary)*–Continued

Code word	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Weight with no ice	9-lb/ft² wind	Resultant weight[1]	Weight with 1/4-in ice	4-lb/ft² wind	Resultant weight[2]	Weight with 1/2-in ice	4-lb/ft² wind	Resultant weight[3]
CANARY	1.1590	.8715	1.5001	1.5981	.5540	1.8914	2.1928	.7207	2.6082
CATBIRD	.9660	.8550	1.3400	1.3983	.5467	1.7014	1.9861	.7133	2.4103
RAIL	1.0750	.8738	1.4353	1.5151	.5550	1.8135	2.1106	.7217	2.5306
CARDINAL	1.2290	.8970	1.5715	1.6787	.5653	1.9713	2.2839	.7320	2.6983
ORTOLAN	1.1650	.9098	1.5281	1.6200	.5710	1.9177	2.2305	.7377	2.6493
CURLEW	1.3310	.9345	1.6763	1.7963	.5820	2.0882	2.4170	.7487	2.8303
BLUEJAY	1.2550	.9443	1.6206	1.7243	.5863	2.0213	2.3491	.7530	2.7668
FINCH	1.4310	.9698	1.7786	1.9109	.5977	2.2022	2.5462	.7643	2.9585
BUNTING	1.3440	.9765	1.7113	1.8267	.6007	2.1229	2.4648	.7673	2.8815
GRACKLE	1.5330	1.0035	1.8822	2.0269	.6127	2.3174	2.6762	.7793	3.0874
BITTERN	1.4340	1.0088	1.8033	1.9300	.6150	2.2257	2.5816	.7817	2.9973
PHEASANT	1.6350	1.0365	1.9859	2.1426	.6273	2.4325	2.8056	.7940	3.2158
DIPPER	1.5220	1.0395	1.8931	2.0308	.6287	2.3259	2.6951	.7953	3.1100
MARTIN	1.7370	1.0680	2.0891	2.2576	.6413	2.5469	2.9337	.8080	3.3430
BOBOLINK	1.6130	1.0703	1.9858	2.1345	.6423	2.4291	2.8116	.8090	3.2257
PLOVER	1.8400	1.0988	2.1931	2.3734	.6550	2.6621	3.0622	.8217	3.4706
NUTHATCH	1.7020	1.0995	2.0763	2.2357	.6553	2.5297	2.9249	.8220	3.3382
PARROT	1.9420	1.1295	2.2966	2.4881	.6687	2.7764	3.1897	.8353	3.5973
LAPWING	1.7920	1.1265	2.1667	2.3369	.6673	2.6303	3.0372	.8340	3.4497
FALCON	2.0440	1.1588	2.3996	2.6022	.6817	2.8900	3.3160	.8483	3.7228
CHUKAR	2.0740	1.2015	2.4469	2.6500	.7007	2.9410	3.3814	.8673	3.7909
	2.1620	1.2608	2.5527	2.7625	.7270	3.0566	3.5186	.8937	3.9303
BLUEBIRD	2.5110	1.3215	2.8875	3.1367	.7540	3.4261	3.9180	.9207	4.3247
KIWI	2.3030	1.3028	2.6959	2.9210	.7457	3.2146	3.6944	.9123	4.1054
	2.9680	1.3928	3.3285	3.6233	.7857	3.9075	4.4341	.9523	4.8352
THRASHER	2.5260	1.3515	2.9148	3.1642	.7673	3.4559	3.9578	.9340	4.3666
JOREE	2.7490	1.4100	3.1395	3.4114	.7933	3.7025	4.2294	.9600	4.6369
	3.5700	1.5758	3.9523	4.3012	.8670	4.5877	5.1878	1.0337	5.5898

ALL VALUES ARE IN POUNDS PER FOOT.

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[1] Includes 0.05 NESC constant.
[2] Includes 0.20 NESC constant.
[3] Includes 0.30 NESC constant.

Table C-6.—*Conductor and overhead ground wire values for NESC light, medium, and heavy loading (U.S. customary)*—Continued

Wire type and size	NATIONAL ELECTRICAL SAFETY CODE 1977 EDITION								
	LIGHT LOADING			MEDIUM LOADING			HEAVY LOADING		
	Weight with no ice	9-lb/ft^2 wind	Resultant weight[1]	Weight with 1/4-in ice	4-lb/ft^2 wind	Resultant weight[2]	Weight with 1/2-in ice	4-lb/ft^2 wind	Resultant weight[3]
STEEL STRAND OVERHEAD GROUND WIRE (7-WIRE)									
3/8 INCH HS	.2730	.2700	.4340	.4627	.2867	.7443	.8079	.4533	1.2264
3/8 INCH EHS	.2730	.2700	.4340	.4627	.2867	.7443	.8079	.4533	1.2264
7/16 INCH HS	.3990	.3263	.5654	.6120	.3117	.8868	.9806	.4783	1.3910
7/16 INCH EHS	.3990	.3263	.5654	.6120	.3117	.8868	.9806	.4783	1.3910
1/2 INCH HS	.5170	.3713	.6865	.7487	.3317	1.0189	1.1359	.4983	1.5404
1/2 INCH EHS	.5170	.3713	.6865	.7487	.3317	1.0189	1.1359	.4983	1.5404
ALUMOWELD STRAND OVERHEAD GROUND WIRE									
8M	.1310	.2040	.2924	.2933	.2573	.5902	.6112	.4240	1.0439
10M	.1650	.2295	.3327	.3379	.2687	.6317	.6663	.4353	1.0959
12.5M	.2080	.2573	.3808	.3924	.2810	.6827	.7323	.4477	1.1583
14M	.2320	.2723	.4077	.4226	.2877	.7113	.7688	.4543	1.1930
16M	.2620	.2895	.4405	.4598	.2953	.7465	.8131	.4620	1.2352
18M	.3060	.3128	.4875	.5134	.3057	.7975	.8764	.4723	1.2956
20M	.3470	.3330	.5309	.5628	.3147	.8448	.9342	.4813	1.3509
25M	.4750	.3893	.6641	.7142	.3397	.9908	1.1088	.5063	1.5190
7 NO. 12	.1036	.1815	.2590	.2566	.2473	.5564	.5651	.4140	1.0005
7 NO. 11	.1306	.2040	.2922	.2929	.2573	.5899	.6108	.4240	1.0435
7 NO. 10	.1647	.2295	.3325	.3376	.2687	.6315	.6660	.4353	1.0957
7 NO. 9	.2076	.2573	.3806	.3920	.2810	.6823	.7319	.4477	1.1580
7 NO. 8	.2618	.2888	.4398	.4593	.2950	.7459	.8123	.4617	1.2343
7 NO. 7	.3300	.3248	.5130	.5424	.3110	.8252	.9103	.4777	1.3280
7 NO. 6	.4163	.3645	.6033	.6452	.3287	.9241	1.0296	.4953	1.4425
7 NO. 5	.5249	.4095	.7157	.7725	.3487	1.0475	1.1755	.5153	1.5835

ALL VALUES ARE IN POUNDS PER FOOT.

[1] Includes 0.05 NESC constant.
[2] Includes 0.20 NESC constant.
[3] Includes 0.30 NESC constant.

Table C-8.—Conductor and standard ground wire values for NESC light, medium, and heavy loading (U.S. customary)—Continued

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